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The World Conference on
Physics Education 2012

WCPE
2012

Editor
Mehmet Fatih Taşar
PROCEEDINGS OF
THE WORLD CONFERENCE ON
PHYSICS EDUCATION
2012

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Mehmet Fatih TAŞAR
Gazi Üniversitesi
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FOREWORD

Physics Education Research (PER) represents the most voluminous, the oldest, and the most rigorous tradition in whole science education research. On the other hand, with its 1380 research article pages, this is the most voluminous book reporting research studies of PER. Thanks to hundreds of its contributors, this book represents the state-of-the-art of PER as of 2012. This book was produced as a result of first World Conference on Physics Education (WCPE) that was held in Istanbul, Turkey during July 1-6, 2012.

Teachers, educators, and researchers, from all continents and 55 countries have attended the WCPE 2012. During the 6 days of the conference there were 249 oral presentations, 27 workshops, 12 symposia, and around 100 poster presentations together with 5 keynote addresses.

On behalf of all participants I wish to thank the sponsors: IUPAP, ICPE, EPS, TÜBİTAK, GIREP, MPTL, Rentech, Vernier, APS, IOP for their support. We are also grateful to AAPT, AsPEN, and LaPEN for their endorsements of the conference.

Like all other PER enthusiasts, I am also looking forward to the second WCPE which is decided to take place in São Paulo, Brazil in 2016 and wish that such a proceedings book tradition continues.

Mehmet Fatih Taşar
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Edward F. Redish, Department of Physics, University of Maryland, College Park, MD, USA

Keynote address presented at the World Conference on Physics Education 2012, Baçeşehir University, Istanbul, Turkey, July 1-6, 2012.

1. Introduction

The stated theme of the first World Conference on Physics Education is "Context, Culture, and Representations." This is highly appropriate for an international conference bringing together physics teachers and education researchers from many nations. As an introduction and overview to the conference, I want to talk about how we might begin creating a way of talking about these complex issues that allows us to build our knowledge cumulatively and scientifically.

In any science, there are typically three complementary approaches that support the science—observation (experiment), practice (engineering), and mechanism (theory). Generally, these three approaches intertwine, inform each other, and provide support for each other. I have illustrated them in figure 1 as the legs of a three-legged stool. And as we all know well, the most important leg of a three-legged stool is the one that’s missing. In PER we have a strong tendency to focus on observation and practice: how do we see our students behaving and how can we figure out how to teach them more effectively?

Figure 1. The three legs supporting scientific knowledge building

The issue of how to build a coherent mental picture (theory) of what happens in a student and a classroom is often the missing leg. While many educational theories exist, they are often narrow prescriptions that provide heuristics rather than frameworks for the development and testing of models that can grow and accumulate knowledge scientifically. (Redish 2003; Redish & Smith 2008)

Part of the problem is, of course, that human behavior is extremely complex. We cannot expect at this stage to have anything like a complete theory. But it is clear that whatever we do, we will have to consider cognition (a model of how thinking takes place) and socio-cultural environments (a model of how an individual interacts with the context and cultures around her). In section 2 of this paper I give the bare outlines of the beginning of such a framework, the resources framework, (Redish & Sayre 2010) including three small experiments that you can carry out for yourself to see the validity of the basic principles.

I then show in section 3 an example taken from our studies following real students carrying out real classroom activities in an algebra-based physics class that demonstrates how this theoretical framework allows us to describe and model an observed strong context-dependence in student behavior by introducing the idea of epistemological framing.

In section 4, I discuss the role of culture. I begin by discussing the impact of diverse scientific cultures on our instruction on non-physics science majors. Currently, the University of Maryland Physics and Biology Education Research Groups are participating in a multi-university multi-disciplinary effort to reform science
education for biology majors and pre-medical students. We have held many hours of discussion with faculty in biology and chemistry and have carried out extensive probes into student perceptions about the relations among the disciplines. These have revealed unexpected cultural differences among the sciences, both for faculty and students, that make it challenging for physics faculty to understand how their non-physicist science, technology, engineering, and math (STEM) students interpret our instruction, and make it difficult for our students to connect what they learn from classes in different departments. The section finishes by briefly addressing the important and interesting question of distinct national cultures and how they can play a role in physics education research (PER).

Section 5 talks about the role representations play in physics and how they interact with cultural and disciplinary questions. Section 6 provides a summary and conclusions.

2. Talking about thinking: A language for discussing context and culture

To understand how to teach students how to learn and understand science we have to understand something of what it means to understand something. It’s important therefore for us to find an appropriate level of description for student thinking. We want to follow the basic precept:

Everything should be as simple as possible – but not simpler! (Attributed to Einstein)

What’s the appropriate level of description for a system as complex as a science classroom filled with human brains? The human brain is an amazingly complex and flexible device, capable of creating art, science, and culture. In our desire to have something tractable and easy to work with, we have to be careful not to create something too simple that does not take into account the full possibilities of the brain’s dynamics and creativity.

Despite its great range and flexibility, the brain operates within constraints and structures that have significant implications for our classrooms. To get a sense of this, let’s consider three exercises that illustrate some of the basic principles in your own brain.

Seeing it in your own brain

The main principles I want to rely on for this talk can be illustrated with three simple experiments that you can do yourself. Try them out before looking at the answers.

**Experiment 1**

In the first experiment, you are shown 24 words (given in the list shown in the figure at the top of the next page). Look at these words for one minute and try to memorize as many of them as possible. Don’t do anything special or organized: just look at the words and try to remember as many as you can. After one minute, look away and try to write down as many as you can recall.

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**Figure 2.** The list of words to try to memorize for experiment 1. (Roediger H. & McDermott K. 1995)

Now look at your list. Check the endnote at the end of this sentence to see if you had either of the two test words on your list. When I give this task to my class, typically more than half of the students put one or both of the test words on their list and are shocked to discover that they weren’t there. They were sure they remembered seeing them!

This illustrates a critical principle of memory: that memory is not veridical. It’s not accurate like a recording,
but rather is “reconstructed” from remembered bits and pieces and plausible “stock items”. There is a lot of psychological data supporting this, going back to Bartlett (1932). More recent support for this result is given in Kotre’s popular summary (1998) and a modern theoretical interpretation (with support from neuroscience experiments) is presented in Buckner & Carroll (2006).

**Experiment 2**

To do our second experiment, you need an internet connection. In this task, a group of six students (shown in figure 3) serve as two teams, one with white shirts and one with black. Each team has a basketball and during the short video they move around quickly, passing their ball among members of their own team. Your task is to see how well you can concentrate by counting the number of passes among the members of the white-shirted team. You have to pay careful attention, since things happen fast!

![Figure 3. Daniel Simon’s concentration task.](image)

Go to the link [http://www.youtube.com/watch?v=IGQmdoK_Zfy](http://www.youtube.com/watch?v=IGQmdoK_Zfy) and maximize the screen without reading any of the text there (or below) until you are done. (Simons & Chabris 1999; Ambinder & Simons 2005)

Many people manage to count the number of passes successfully, but fail to see the dramatic events and changes that take place during the clip and are identified at the end. This surprising phenomenon is called *inattentional blindness* – the fact that when you are paying attention to one thing you think is important, you may miss other important things. This is the psychological core of the phenomenon that I refer to as *framing*. It will play a critical part in my interpretation of the role of culture in the classroom.

**Experiment 3**

Our third experiment demonstrates that our brains have difficulty in managing tasks of too high a complexity at one time. For this task you will need a partner. Have your partner read you the following strings of numbers and you try say them back in reverse order. So if your partner says “123” you respond “321”. Now try it with the following number strings:

- 4629
- 38271
- 539264
- 9026718
- 43917682

Get the idea? It gets harder and harder and above a certain point it’s impossible. Of course you can develop techniques to do this task, but all of my experiments are designed to show that the untrained brain has limitations. This limit on processing capacity has been known for more than 50 years since George Miller (1956) proposed his limit of “7 ±2” and is the basis of the important psychological construct of “working memory” (Baddeley 1998).
To see that this result has implications beyond this trivial “zero-friction” example, take a look at A. H. Johnstone’s Brasted Lecture (1997). In it, he reports on a chemistry exam on the topic of the mole (Avogadro’s number of molecules) set by the Scottish examination board and given to 22,000 sixteen-year-old students. Student success is plotted as a function of the sum of (1) the pieces of information given in the question, plus (2) the additional pieces to be recalled, plus (3) the number of processing steps required. The result is dramatic and shows a sharp drop-off at six pieces of information, consistent with Miller’s suggestion. The result is shown in figure 4.

![Figure 4](image.png)

**Figure 4.** Dependence of the success of chemistry students on the number of elements in the question. (Johnstone 1997)

**Implications**

These little experiments illustrate a few basic principles:

1. Memory is not just recall but is reconstructive and highly dynamic.
2. Selective attention matters.
3. Working memory (what you can hold and manipulate in your mind at any one instant) is limited.5

These principles have important implications for the role of context, culture, and the need for the use of external representations. Being aware of our students’ spontaneous behavior can help us learn to devise activities to help them learn ways of thinking to overcome them. Of course these don’t tell the whole story. For more discussion and lots more references, see (Redish 2003; Redish & Smith 2008).

**The cognitive structure**

The basic principles are just a first step. To figure out how they work in the brain dynamically, we need a more mechanistic picture. I’ve outlined a model of this based on neuroscience and psychology research in figure 5. Let’s imagine that the brain is presented with a straightforward set of data: the perceptual signals associated with holding a cup of Turkish coffee. These include a variety of sensations: (1) visual – a pattern of signals arriving on the retinas of your eyes, (2) haptic – the sense of touch including the feel, texture, and weight of the cup in your hand, (3) olfactory – the smell of the coffee, and (4) memory – your knowledge of the cup, including how it tastes, what the effect of the coffee might be on you, and your social knowledge about how and when to drink it – and when to stop drinking it so you don’t get a mouthful of grounds.

The first step in the way the brain appears to work is that the basic sensory data is processed to create a single coherent perceptual construct and generate some immediate and strong associational knowledge.
While it is doing this, it sends signals to the judgment and decision-making part of the brain, the prefrontal cortex – just behind your forehead. This part of the brain accesses information from long-term memory to decide what to do with the data. This is where your knowledge about the way the world works is brought in. Selective attention (such as in experiment 2) happens here and other perceptions and associations (such as in experiment 1) can now be linked to the original percept. (For more on the details of this process and neurologically explicit examples of it, see (Fuster 2003), (Bar et al. 2006), and (Mesgarani & Chang 2012).)

Figure 5. Dynamical structure of the brain’s response to input data.

This model sets us up the structure for the phenomenology I will use to analyze and describe context, culture, and representations: associations and control of those associations.

- **Associations** – Activity in the brain consists of turning on clusters of neurons. These clusters link to other neurons and send out signals that tend to activate (or inhibit the activation of) other neurons, activation of one cluster may induce activation of other clusters leading to interpretation and meaning making.

- **Control** – The feedforward and feedback of signals to and from the prefrontal cortex and long-term memory may activate or suppress the activation of associational clusters.

The control level is where students’ assumptions, expectations, and culture draw on their broad knowledge of appropriate behaviors to affect what they do in our classrooms. To understand how to talk about this, let’s consider how the behavior of an individual is imbedded in a socio-cultural environment and how this environment affects behavior.

**The cultural structure**

The behavior of any human being is immensely complex. It can be analyzed at scales, ranging from the very small (how many neurons are being activated) to the very large (how does it depend on the presence of highly structured modern technology or the modern nation state). It responds to the individual’s knowledge of the human social world, which comes from many sources and scales. I display one way of thinking of this in figure 6. I use a staircase as a metaphor for resolution (or “grain size”): when looking at something while standing at the bottom you can see all the local detail. The higher up you are, the less detail you see – but you are able to discern broader emergent patterns. In a burst of overindulgent nomenclatural enthusiasm I have dubbed this the cognitive/socio-cultural grain-size staircase.
Figure 6. The cognitive/socio-cultural grain-size staircase.

On the lowest level we see neurons and their functioning – the fundamental matter of which behavior is made up. When we move up a step we ask ourselves about the basic psychological mechanisms of behavior – what they are and how they develop. Another step up takes us to basic behavioral phenomenology – what individuals know about the physical world and how they interact with it. The next step moves beyond the individual and places him or her in the context of a small group. Beyond that, we consider the individuals’ relation to the broader local culture of the environment – their knowledge and experience with classrooms and school and their understanding of appropriate behavior in that context. The classroom itself then gets imbedded in multiple cultures – the culture of the discipline being taught and the way schooling is imbedded in the broader culture of the locale – how schooling tends to be viewed by other individuals in the society, how it relates to employment opportunities, how one’s position as a member of various subgroups in society affects one’s behavior, and so on. Power relations, stereotypes, and other important factors come in at this level. At a step up, we might begin considering the behavior of groups of individuals whose function has to be seen as a group. A software development corporation may have coherent capabilities that no individual possesses (Brown & Duguid 2006); a battleship may know how to navigate but no single individual may have that knowledge (Hutchins 1996).

Each level is emergent from the level below it; the critical behaviors seen at a given level are a result of structures at lower levels, but they may not be easily visible or even discernable in a study of the lower level.

But the important part of this staircase analysis for us as science educators is that the behavior of the individual student in our classroom is affected – often strongly – by the knowledge they bring to the classroom. And their knowledge and perception of all the upper levels of the staircase can play a critical role, serving as control structures for what behaviors students engage in and what they avoid. I show this in the figure as arrows looping back to the basic behavioral level. In order to talk about how this works, I adapt the process known as **framing** from anthropology and sociolinguistics.

**Framing:** The interaction of the cognitive and the cultural

Socio-cultural effects on the classroom have been studied extensively for many decades, but often a critical point is not made explicit. It’s not just the socio-cultural environment that matters: it’s a student’s perception of the socio-cultural environment that affects that student’s behavior. This requires us to not simply look at the environment and interpret it through our own perceptions, but asks us to consider what socio-cultural knowledge the student brings to our classroom and how that knowledge is used. As in our experiment 2, if our students don’t perceive what we have set up for them or asked them to do, it might as well not be there.
The anthropologist Erving Goffmann (1986) focused much of his research on the subject of figuring out how people interpret and respond to the social environments they find themselves in from moment to moment. He suggested that people are continually asking themselves the question, “What’s going on here?” (Though not necessarily consciously.) The answer to that question then controls (again, not necessarily consciously) what behaviors the individual activates. Goffmann referred to the process of answering that question by drawing on experiences stored in long-term memory, as framing. The concept has been further developed in sociolinguistics (Tannen 1993) and in other fields as well (MacLachlan & Reid 1993). For an extended discussion of how it applies in physics education, see Hammer et al. (2004).

Framing can have many components: for example, affective (How will I feel about this class?), social (Who am I going to interact with and in what ways?), and epistemological. This last is particularly important for a science class where we are trying to build a students’ knowledge. I consider epistemological framing to be the process that generates each individual’s answer to the questions:

What is the nature of the knowledge we are learning in this class and what do I have to do to learn it?

The concept of framing matches well with the more recent developments I cited above in neuroscience showing that sensory data is put in context by passing signals through the pre-frontal cortex, which draws on long-term memory to adjust attention and to activate knowledge and decisions of how to behave. Framing is what you did when you focused your attention on the passes in experiment 2 and as a result wound up not seeing other elements that were interesting and possibly important. In that case, in my instructions I encouraged you to frame the task as a concentration one, which encouraged you to ignore (or even suppress) everything else that might be happening. But problems occur in a classroom when students bring in their own expectations that may result in their ignoring messages that you think you are sending explicitly; expectations like, “I know how a science class works. I don’t have to read all these pre-class handouts.”

3. Context

We now have a language to talk about how students respond to context in our classrooms. Let’s consider a specific detailed example from the work of Brian Frank (2009). This is taken from a lesson in a class in Introductory Physics (algebra based) at the University of Maryland. The classes are taught in fairly traditional structure, with three hours of large lecture (N ~ 200) per week, one hour of small-group recitation (N = 24), and two hours of laboratory. The population was largely life and health science majors. The class had been modified to place more emphasis than usual on epistemology – How do we know? Why do we believe? (The modifications are described in detail in (Redish & Hammer 2009).) The specific example I want to describe occurs in the recitation section, which were run as Tutorials.

Tutorials

The term “Tutorial” has a wide variety of meanings in different countries around the world. But when a physics education researcher in the USA talks about “Tutorials” they almost always mean “University of Washington-style Tutorials.” These are lessons developed over many years by Lillian McDermott and her colleagues at the University of Washington (1998). These lessons are carefully tested and refined through multiple cycles of research, curriculum development, and instruction. Tutorials focus on well-defined common student difficulties and typically help students understand how to develop qualitative reasoning.

Students doing these lessons work in groups of 3-5 facilitated by a teaching assistant (TA) – ideally about 1 TA per 15 students. The assistant is trained to understand what difficulties the student can be expected to encounter and is taught to encourage the student to explore and discuss their own ideas. (For a detailed description of UW Tutorials and references to their research papers on Tutorial development, see chapter 8 of my book, Teaching Physics with the Physics Suite (2003).)

Our example is drawn from our modification of an early lesson in kinematics.
An example

For the lesson on velocity, we use a standard device (shown in figure 7). A long thin paper tape ("ticker-tape") is attached to a low friction cart (shown at the left) and run through a "tapping device" that taps a sharp point onto the tape through a piece of carbon paper at a fixed rate. The cart is allowed to accelerate slowly down a long ramp and the tapping device creates dots on the tape whose spacing indicates the cart’s speed.

The tape is then cut into segments of six dots each. Since the cart accelerated slowly, 6 dots (representing about two-tenths of a second) look as if they are representing a constant speed. Each student receives a segment as shown in figure 8 below.

Figure 7. Pasco low-friction cart and ticker-tape tapper.

Figure 8. Samples of ticker tape given to the students in Tutorial.

The first question the students are asked in the lesson is: "How does the time taken to generate one of the short segments compare to the time to generate one of the long ones?"

Since the marking device taps at a fixed rate, the answer is trivial: since they each have six dots, they each took the same amount of time to make. Interestingly, this is not what we saw the students say in our videotapes of the lessons. Here are some transcripts:

Group 1
S1: Obviously, it takes less time to generate the more closely spaced dots.

Group 2
S2: (Reading) “How does the time taken...” It’s shorter! (Huh!)
S3: Yeah. Isn’t it pretty much – The shorter ones are shorter.

Group 3
S4: (Reading) “The time taken to generate one of the short segments...” It’s shorter!

Group 4
S5: Well it takes less time to generate a short piece of paper than it does a long one. (pause) I would assume. (pause) I don’t really know how that thing works. [The last two comments are ignored by the rest of the group.]
It’s quite dramatic watching one group after another give the same obviously incorrect answer, without hesitation and mostly confidently. This looks suspiciously like a standard “misconception”. But the last example we quoted gives a hint as to what’s going on.

If we go a bit further into the video, we find the next question in the lesson shifts the context for the group. The result is that they bring a different approach to bear. They are asked, “Arrange the paper segments in order by speed. How do you know how to arrange them?” Here’s a typical response from one of the groups.

S1: Acceleration! It starts off going slow here, [pointing to a short segment] then faster, faster, faster [pointing to a long segment].

S2: No, no! Faster, then slower, slower, slower! This is slow. [pointing to a long segment]

S1: When it gets faster it gets farther apart. That means the paper’s moving faster through it. [gestures] So it’s spaced out farther.

S2: Wait. Hold on. [gestures to TA]

S2: [to TA] Is the tapper changing speeds or is the paper moving through it changing speeds?

TA: The tapper always taps at the same speed.

S1 and S2 [together and pointing at each other]: Ahhh!

We saw this again and again. At the beginning the students gave a quick answer – longer tapes take longer times, shorter ones take shorter. Just a few minutes later, the light dawns and they all get it right.

What is changing when the students in these groups shift their behavior in response to a (very slightly) changed context? I suggest that the easiest way to describe what is happening is as epistemological re-framing.

Is it a misconception?

In PER we often have a tendency to refer to common errors that students bring into the classroom as “misconceptions”. I don’t have a problem with this, but I would like us to take a fine-grained view of them. I define a misconception as a student error that is commonly and reliably activated in a given context. This gives us more flexibility and encourages us to understand what is happening in detail – to consider how the student is responding to the context – rather than using the term to close off further consideration of what the student is actually bringing to the task. Misconceptions can have structure, not just be an irreducible gallstone that needs to be removed. Misconceptions can be robust and hard to undo, but sometimes they are created on the spot and are highly context dependent.

In our example, at the start of the lesson many students have the epistemological assumption that they will be able to generate a correct answer by simply looking at the question and drawing the most immediate and natural response – essentially by an immediate association without carefully considering the mechanism of what is happening (“one-step thinking”). What they get is a phenomenological primitive...
“more is more”, which they map in this situation into “longer tape takes longer time” (diSessa 1993; Redish 2003). This feels right to them and they move on.

The misconception in this case isn’t actually a misunderstanding about the nature of velocity; rather it’s a **framing error** that is common and reproducible in this context. The misconception here is epistemological rather than conceptual: students assume that the answer can be generated directly by fast thinking without any careful consideration of the mechanism. The student in group 4 expressed a framing caveat: essentially, “We might have to consider the mechanism here.” The later questions on the worksheet can’t be answered without considering the mechanism, so a frame shift was needed. This led the students to go back and reconsider (and correct) their answer to the first question.

For most physics teachers it will be a surprise that our students might “miss the gorilla in the classroom” and assume they didn’t need to think about the mechanism of what’s happening – especially since the lesson begins with the TA describing the mechanism! But selective attention can cause them to not only focus on particular aspects of a task but to ignore aspects their instructors might consider natural and critical.

Epistemological framing – what the students think is the kind of knowledge they are seeking and what they think they have to (or are allowed to) use to get it often plays an important role. If we ignore the issue of epistemological framing, we might misinterpret where a common student problem lies and have trouble creating an effective lesson – or fail to understand why a particular lesson is effective. For more examples, see my Varenna lecture, (Redish 2003)

Here’s the takeaway message:

*Student responses don’t simply represent activations of their stored knowledge. They are dynamically created in response to their perception of the task and what’s appropriate. As a result, their behavior may have a complex structure. The (often unconscious) choices they make as to how to activate, use, and process knowledge are often determined by social and cultural expectations (framing).*

### 4. Culture

**The disciplines**

The students in the example in the previous section brought a rather local expectation into their classwork – that they could get the answers without thinking about the mechanism of what’s happening. This is likely to come from one step up in the “cognitive/socio-cultural grain-size staircase” – from their experience in the culture of other classes, particularly their previous science classes. In some cases, difficulties arise from additional steps up. In my next example, disciplinary cultures play a dramatic (and surprising) role in reforming an introductory class for biology and health-science majors.

*Teaching physics is primarily in service to other disciplines*

Physics departments often focus their concern about teaching on their majors. These students are of course important; they are our intellectual progeny and the future of our discipline. But we may tend to forget that physics teaching at the university level is primarily in service to other larger disciplines. In the Physics Department at the University of Maryland we have a total of about 250 undergraduate majors and a comparable number of PhD graduate students. But every semester we teach nearly 1000 engineers and 1000 biology majors in our introductory service courses. A similar pattern can be found at most large research universities in the USA, and a brief email survey of my friends and colleagues in other countries indicate that this is widespread around the world. This is a result of the structure of science today. Figure 10 shows the distribution of PhD scientists in the USA in 2006. Physics is the small blue bar – smaller even than geosciences. Our primary service clients are biology (the largest bar in green on the left) and engineering (the red bars).
Many universities in a number of different countries have seen significant cutbacks (or even eliminations) of their physics departments as a result of losing students. How can this be? Don’t the engineers and biologists need to study physics? It’s basic!

Unfortunately this is an indication that our perceptions of our profession and teaching may be culturally biased. At a recent conference on interdisciplinary science and math education, I had given a talk on the topic of creating a “Physics for Biologists” class (Redish 2012). Here are two quotes from a physicist and a biologist later heard and transcribed by my grad student, Ben Geller:

**Physicist:** This whole ‘physics for biology’ idea makes me very uncomfortable. What’s next? ‘Physics for mechanical engineers’ or ‘physics for electrical engineers’? Where does it end? I could see maybe having a physics class for all students and then having a few tailored recitation sections where students focus on applications to their various fields, but I’m uncomfortable with ‘physics for X’ as an idea. We should be conveying how we view physics to everyone.

**Biologist:** I guess the physics for biologists idea may be a step in the right direction, but for it to be useful it has to go much further and be entirely revamped. It has to be very narrowly focused on those ideas that biologists see as essential, not just removing a few topics. Unfortunately, physicists generally have a profound ignorance about biology, so I’m not sure they are the right folks to be doing it. I can teach the relevant physics myself.

This suggests a dramatic – and chilling – culture gap between the perceptions of a physicist and a biologist about how to teach physics for service students. These comments are not unusual or unique. I have heard comparable ones from many physicists and biologists. If we are to keep teaching physics to biologists (and engineers) we need to understand their culture – and their perceptions of physics and how it is of value to them.

As a result of a recent opportunity to participate in a national reform project, I have begun to learn something about disciplinary cultural differences, their impact on our instruction, and how these differences are viewed by the biology faculty (gatekeepers to our classes) and by our biology students.

**Calls for change from the biologists: The challenge**

For nearly a decade the biology community has been calling for an upgrade of undergraduate instruction for biologists (National Research Council [NRC] 2003). In 2009, Association of American Medical Colleges (AAMC) working with the Howard Hughes Medical Institute (HHMI) published *Scientific Foundations for...*
Future Physicians (AAMC-HHMI 2009) – a call for rethinking education for biologists and pre-medical students in the US to bring in more and better coordinated science – biology, math, chemistry, and physics, and to focus on scientific skills and competencies. (For addition reports on articles concerning the reform of biology education, see the NEXUS Documents on Biology Education Reform.)

The result was that HHMI funded Project NEXUS: the National Experiment in Undergraduate Science Education, a 4-year, 4-university $1.8 M project (NEXUS-HHMI 2012). At the University of Maryland, College Park (UMCP) we have opened an interdisciplinary conversation to create a physics course designed to meet the needs of biologists and pre-health-care-professionals (NEXUS-UMCP 2012). We’ve put together a team of nearly 40 professionals, including physicists, biologists, chemists, and education researchers both on and off campus. Over the past two years we have held hundreds of hours of interdisciplinary conversations and negotiations among subgroups of this team. We quickly discovered that creating an interdisciplinary physics course that meshed with what was being taught in biology and chemistry and met the needs of life science majors was not going to be simple.

It turned out there were significant cultural differences between biologists and physicists. Biologists saw most of the traditional introductory physics class as useless and irrelevant to biology – and the claim made by the physicists, “We can apply physics to biology examples,” as trivial and uninteresting. Physicists saw a coherent structure with no room for change.

After much discussion and negotiation, we came to a better understanding of what it was the biologists needed and how the disciplines perceived the world and their science differently.

Culture differences between physics and biology

What we have learned from our extensive interdisciplinary conversations is that for us to meet the needs of biologists in learning physics, there is much more than changing the table of contents and the prerequisites. Each scientific discipline brings broad cultural assumptions, approaches, and epistemologies that are unique and strongly affect the way that both faculty and students frame the activities in a science class. Here is a list of some of the characteristics that we found were distinctive in physics and biology with an emphasis on how the introductory classes are treated.

Physics: Common cultural components

- Introductory physics classes often stress reasoning from a few fundamental (mathematically formulated) principles.
- Physicists often stress building a complete understanding of the simplest possible (often abstract) examples – and often don’t go beyond them at the introductory level.
- Physicists quantify their view of the physical world, model with math, and think with equations.
- Physicists concerns themselves with constraints that hold no matter what the internal details. (conservation laws, center of mass, ...)

These elements will be familiar to anyone has ever taught introductory physics. What is striking is that we usually do not articulate what we are doing – and none of these elements are typically present in an introductory biology class. Biologists have other concerns.

Biology: Common cultural components

- Biology is irreducibly complex. (Oversimplify and you die.)
- Most introductory biology is qualitative.
- Biology contains a critical historical component.
- Much of introductory biology is descriptive (and introduces a large vocabulary)
- However, biology – even at the introductory level – looks for mechanism and often considers micro-macro connections.
- Biologists (both professionals and students) focus on real examples and structure-function relationships.
These issues don’t match well with what we tend to do in intro physics. Though we do focus on mechanism, it
rarely is explored at the atomic or molecular level. The demand for realism and structure-function relationships
was a particular sticking point for us. The physicists on our team often found an example or explanation
“cute” or “enlightening” if it helped explain a relationship. The biologists mostly were uninterested in such
examples unless they could see how it had implications for real-world examples. Many of our biologists
considered traditional physics examples, such as the simple harmonic oscillator (mass-on-a-spring), irrelevant,
uninteresting, and useless until we were able to show its value as a starting-point model for many real-world
and relevant biological examples. This required making it clear from the first that a Hooke’s law oscillator was
an oversimplified model and illustrating how it would be modified for realistic cases.

**Restructuring Introductory Physics for the Life Sciences**

As a result of our discussions and negotiations we proposed to change both the culture and the content of
the class so as to make the value more obvious both to biology faculty and to biology students. Here are
some of the “cultural guidelines” we have chosen.

- Organize the course and select examples so that both biology faculty and students feel that it has
  obvious value for upper division biology courses.
- Do not assume this is a first college science course. Make biology, chemistry, and calculus pre-
  requisites.
- Do not assume students will have later physics courses that will “make things more realistic”.
  Explicitly discuss modeling and the value of understanding “simplest possible” examples.
- Choose different content from the traditional by including molecular and chemical examples and
topics of more importance to biology.
- Maintain the crucial components of “thinking like a physicist” – quantification, mathematical
  modeling, mechanism, multiple representations and coherence (among others).

Physicists often assume that the content of an introductory physics course is almost all “privileged” –
you have to do it all to get a start in physics. What is often missed is that the standard content is not a
complete introduction; it is already a selection. Our current selection tends to favor items that can be done
mathematically completely and simply. Topics that are of great importance in biology – such as motion of
and in fluids, diffusion, and electrical properties of matter – are suppressed; I suspect in part because a full
mathematical treatment of these topics lies at the graduate level. But these topics are needed – and used! –
in introductory biology and chemistry classes. We have decided that we can do something useful with these
topics by including some phenomenology while still maintaining the crucial components of “thinking like a
physicist.” As a result, we are attempting to include significant treatments of the following topics in our class.

- Atomic and molecular models of matter
- Energy, including chemical energy
- Fluids, including fluids in motion and solutions
- Diffusion and gradient driven flows
- Dissipative forces (drag & viscosity)
- Kinetic theory, implications of random motion, and a statistical picture of thermodynamics

These topics are difficult and cannot be done without considerable effort (and some needed education
research). As a result, some traditional elements have to be suppressed. After much discussion we have
decided to eliminate or dramatically reduce our coverage of the following elements.

- Projectile motion
- Universal gravitation
- Inclined planes, mechanical advantage

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Some of these decisions are quite painful to someone (like myself) who has been working on finding good ways to teach some of these topics for many decades. We have had to think carefully about why we felt strongly about each topic. For example, we concluded that projectile motion and inclined planes had significant value as a vehicle for teaching students about vectors and components, but little value as core models for anything a biologist would use. As a result, we chose to reduce these topics significantly and replace them by an early treatment of static electrical forces (often in molecular examples) with careful training with vectors.

Note that for almost every topic that we cut back on, we could imagine practical applications for biologists or medical professionals that relied on one or more of them. But one cannot cover everything without becoming so superficial that our students only learn words, not ways of thinking. We decided that most biologists needed to be able to think about and understand basic biological mechanisms more than they needed to understand how their tools and measuring devices (that are treated as “black boxes” by most professionals) work.

Bridging the culture differences between physics, biology, and chemistry has been challenging. But even as we make progress in connecting at the faculty level, how our students respond to our attempts to bridge the cultures of the scientific disciplines also needs to be understood.

Student attitudes toward interdisciplinarity

From each level of their experience with a discipline – small group interactions, STEM classes, broader school experiences – students bring control structures (framing) that tell them what to pay attention to in the context of activities in a science class. Their framing of an activity affects how they interpret the task and what they do.

We have studied student responses to interdisciplinary activities combining physics and biology in two contexts: in an organismal biology course that is attempting to use a principle-based approach that includes a lot of physics, and in our NEXUS physics course that is attempting to teach physics principles in a way that uses authentic biological contexts. In both cases we have measured student responses and attitudes in a variety of ways. There is not space to go over these observations in great detail, but I will point out two examples that illustrate how our cognitive / socio-cultural / framing analysis helps us understand some of the often surprising issues that arise.

Problems with using physics in a biology course

Ashlyn is a student in the Organismal Biology course mentioned above. In one lesson, the instructor produced the implication of Fick’s law: that the distance something diffuses (in one dimension) is proportional to the square root of the time. Later in the class, Ashlyn made the following comment in an interview.

I don’t like to think of biology in terms of numbers and variables.... biology is supposed to be tangible, perceivable, and to put it in terms of letters and variables is just very unappealing to me.... Come time for the exam, obviously I’m going to look at those equations and figure them out and memorize them, but I just really don’t like them.

I think of it as it would happen in real life. Like if you had a thick membrane and tried to put something through it, the thicker it is, obviously the slower it’s going to go through. But if you want me to think of it as “this is x and that’s d and this is t”, I can’t do it.
Actually, she “can” do it, because she also took my physics class (previous to our reform to match it to biology) and did very well. I believe this is clearly a framing problem. Based on her experience and expectations, she sees reasoning with mathematics as unnecessary – and even distasteful – in biology.

Interestingly enough, this is not the end of the story (Hall et al. 2011). Later in the interview, Ashland got excited about an exercise later in the class in which the implications of surface to volume ratio for biology were explained mathematically. A small wooden horse was constructed of a few blocks of wood and supported with dowels for legs. It stood quite nicely. A second horse was then produced in which every dimension was scaled up by a factor of 2. When placed on the ground the legs broke, unable to hold up the extra weight. This larger wooden horse is shown in figure 11.

![Image of wooden horse](image1.png)

Figure 11. Jeff Jensen demonstrating his scaled up wooden horse in Org Bio.

Here is how Ashland described her response to this activity:

> The little one and the big one, I never actually fully understood why that was. I mean, I remember watching a Bill Nye episode [TV science program in the US] about that, like they built a big model of an ant and it couldn’t even stand. But, I mean, visually I knew that it doesn’t work when you make little things big, but I never had anyone explain to me that there’s a mathematical relationship between that, and that was really helpful to just my general understanding of the world. It was, like, mindboggling.

This pair of statements leads us to an interesting take-away message.

> Biology students bring cultural/disciplinary expectations to their classes that lead to framings of activities that may get in the way of trying to create interdisciplinary instruction – but it can be context dependent. If the activity is perceived as doing work for them, students can reframe their view of what is going on.

Problems with using biology in a physics course

During the first trial of the reformed NEXUS class in the 2011-12 academic year, we made an attempt to deal with some of the issues that had been raised in our negotiations with the biologists and chemists. One problem that they identified was that students were highly confused about chemical binding. The biologists often used the language of “energy stored in chemical bonds.” The chemists (and physicists) were uncomfortable with this language since a “bond” implies a negative energy and that energy has to be put in in order to sever the bond. A critical example is the hydrolysis of ATP. The molecule adenosine triphosphate (ATP) has a weakly bound phosphate cluster. In a watery environment a small amount of input energy can break this bond; the phosphate can then bind with water, which forms a strong bond. As a result, significant amount of energy can be made available to do a variety of kinds of biologically relevant work. This reaction is fundamental to biology and ATP is often referred to as the energy currency of the cell. The process is illustrated in figure 12.
Chemistry education researchers often identify as a “misconception” that students assume “energy is stored in the ATP bond” whereas really the energy comes from going from the weaker ATP bond to the stronger OH-P bond (Galley 2004).

After going through a series of activities that bridged from everyday situations (a skateboarder in a dip) to simple chemical examples, we tried a question from W. Galley’s paper in the chemistry education literature (figure 13) in a quiz early in the second term of the class.

An O-P bond in ATP is referred to as a “high energy phosphate bond” because: (choose all correct answers.)
A. The bond is a particularly stable bond.
B. The bond is a relatively weak bond.
C. Breaking the bond releases a significant quantity of energy.
D. A relatively small quantity of energy is required to break the bond.

Answers B and D are considered correct and answer C is considered representative of a serious misconception.

Our students did a bit better than the chemistry class reported by Galley – but not much. In our class 79% chose the “misconception” C compared to 87% in the chemistry class; and 47% chose the “correct” answer B compared to 31% in the chemistry class. However, there was an interesting result. Almost 1/3 of the students gave B and C as answers – apparently contradicting themselves. Why?

A possible answer appeared in an interview with Gregor, a student who joined the class in the second term and was often explicitly metacognitive about his thinking. Gregor chose BCD for his answers and explained his choice this way.

I put that when the bond’s broken that energy is released. Even though I know, if I really think about it, that...you always need to put energy in ... to break a bond. Yeah, but -- I guess that’s the difference between how a biologist is trained to think, in like a larger context and how physicists just focus on sort of one little thing.... I answered that it releases energy, but it releases energy because when an interaction with other molecules, like water primarily, and then it creates like an inorganic phosphate molecule that...is much more stable than the original ATP molecule.... I was thinking that [in the] larger context of this reaction [it] releases energy.

This is a very interesting explanation. Gregor explicitly describes his loss of points on the quiz as a framing error. When looked at it from a physics framing, one assumes that one should isolate the molecule and talk about it as if it were in a vacuum. When considered however from a biological framing, the molecule is always in water so the availability of water molecules – and the second part of the reaction – can be taken for granted. In this framing of the context all three of Gregor’s answers can be seen as correct.
This last example pulls together a number of the threads we have been discussing through this paper. The disciplines often make different epistemological assumptions so that a given context may be seen in different ways depending on what framing is used. This leaves us with a take-away message for this section.

*In considering students’ responses in interdisciplinary situations (indeed, in ANY situations), we have to be aware of possible framing differences that arise out of the differences between disciplinary cultures.*

**International Studies**

Disciplinary cultures are not the only steps in the cognitive/socio-cultural grain-size staircase that affect how our students perceive activities in our classroom – how they frame the activities and behave accordingly. The broad cultural elements we all learn from being part of a community – a profession, a nation, a family, a religion – plays a role in how we interpret what we see and do. At an international conference it is particularly appropriate for us to consider what we can learn from international and intercultural comparisons.

Physics education research and science education has a long history of international comparisons. The TIMSS, PISA, and other studies have received international attention. The abstract volume for this conference contains many multi-national comparative studies. While these are of considerable interest, what is of even more interest is the following:

*When comparative international studies find significant differences between comparable populations in different countries, how do we figure out what is responsible for those differences?*

Until we have answered that question, we can’t really tell what a nation or school district might need to do in order to improve their teaching and learning. While there have been some attempts to explain international and cultural differences, my sense is that most studies are still at the stage of documenting the differences and don’t go much beyond speculation in considering what causes the observed differences.

Let me briefly cite one example of a study that our research group has just begun. In this study we try to use the variability of situations from one country to another in order to probe variations that would be difficult to examine in a single school system.

One issue that arises when considering students’ epistemological framing is, “Where and when do students develop frames and how easy is it to ‘resurrect’ a long-unused frame?”

One of the big problems in implementing Tutorial classes such as described in section 3, is that students often bring serious epistemological misconceptions to the class. They have had so much experience with classes where all that mattered was the answer, that they have a hard time focusing on reasoning – why we choose a particular answer. Many have had high school physics classes in which plugging numbers into poorly understood equations sufficed to earn a solid A. As a result, they have difficulty framing the Tutorial as an activity that will contribute significantly to their physics achievement. (This despite extensive data that show much stronger learning with Tutorials than with traditional problem solving recitations (Redish, Saul, & Steinberg 1997).) The result is often discontent and serious resistance. Making Tutorials work in the US often requires careful effort, training TAs to understand the challenge and helping them to learn how to help students make the transition to a more effective epistemological framing of the worksheet activities (Goertzen, Scherr, & Elby 2009, 2010a, 2010b).

Many of our students at the University of Maryland appear not to have had significant experience in qualitative groupwork in which their own ideas were valued. The result is often significant initial resistance to the kind of activities in Tutorials. Would the situation be different if they already possessed similar experiences and had available an epistemological framing of such activities that they were comfortable with?

It would be difficult for us to find a significant sub-population among our students in the US who have had such experiences. However, different national instructional models allow an exploration of this issue. In Japan, students often are exposed to groupwork in which their own ideas are explored and valued during
elementary school. But in middle and high school, high-stakes testing drives the educational model towards more rote learning, drill and practice, and straight lecturing (Stevenson & Stigler 1992). A graduate student in my group, Mike Hull, wondered whether students in Japan would respond differently to Tutorials than American students and whether or not they would perceive their elementary school experience as helping them adjust to the new environment (Hull 2013).

In the Spring of 2011, Mike visited Gakugei University in Tokyo, where he helped Professor Uematsu translate and implement Tutorials in a class of 140 undergraduate pre-service teachers. He did extended interviews with 28 of these students. He found that students took to the Tutorials immediately, without the resistance observed in the US. There is evidence to suggest that many of the students were able to reach back to their elementary school experience and activate an epistemological frame that expected them to interact with each other and use and evaluate their own ideas. One student, when asked why it was so easy to adjust to Tutorials, responded,

Even though so many years have passed in middle and high school where we were being taught uni-directionally by a teacher, even though we took those classes, the chatting, talking, and solving problems together that we did in elementary school was fun. Talking with people about things that you know, and if that person knows something you don’t, he can teach you… since we know the importance of that, we quickly got used to [Tutorials] I think: we have experience from elementary school.

Here’s the take-away message:

Inter-cultural comparisons provide us with extraordinary opportunities for carrying out “experiments” that could not be done in classrooms in a single culture. These experiments may help us to better understand the developmental trajectory of the epistemological frames students bring to our classes.

5. Representations

The last of the three topics in this conference’s theme is representations. This fits in extremely well with the issues of context, culture, and with our model of thinking. If you tried experiment 3, you might have been surprised at how quickly your brain ran out of processing and storage space. After all, as a physicist you are likely to have generated arguments and mathematical derivations that ran over many pages — and it felt like you could hold it all in your head at once. But this is where external representations come in. Off-loading cognitive information onto external visualizations allows us to create much more complex reasoning than unassisted working memory can handle. The brain can do fast switching, so having things represented externally allows us to “roll in” and “roll out” knowledge and make connections that are otherwise too much for us to handle. The external elements essentially become a part of our cognitive processes.

Since physics makes so make effective use of so many different kinds of representations, there are numerous studies of how students interact with them and how to help students frame them as coherent (like with the cup of Turkish coffee, merging multiple perceptions to create a single sense of the phenomenon). I don’t have much space to discuss this, but I want to make two important points. First, that our use of external representations is woven deeply into the culture of physics, and second, that representations are strongly cultural. Disciplinary traditions and assumptions about representations can lead to conflict in trying to create an interdisciplinary approach to teaching the various sciences to a single population of students.

Recognition is much easier than recall. As a result, we can think effectively using external representations. My favorite example of this is using computers. In my house, both my wife and I create PowerPoint presentations for our work. Sometimes, I know how to do something that she doesn’t and I’ll be called on to explain. Often, I can do the task but I can’t tell her how to do it. I have to sit down at her computer and show her. The problem is that I recognize which menu I will need to use and, when it opens, I will recognize which item I need to choose. Then I recognize what I have to enter in the dialog box that appears. But without interacting with the program itself, I don’t remember what the steps are. I don’t know how to carry out the task, but the program and I together know how to do it.
In physics, we often “think with equations,” using external symbolic representations not just to calculate, but to organize and provide easy access to a large amount of qualitative and conceptual knowledge. Here’s an example (an excerpt from the text materials for our NEXUS class) discussing the knowledge represented in the equation expressing Newton’s second law, externally represented in mathematical form as:

$$\ddot{a}_A = \frac{\vec{F}_{\text{net}}}{m_A}$$

Figure 14. Newton’s second law represented mathematically.

Each bit of this seemingly simple-looking equation codes for activating bits of conceptual knowledge about motion.

1. $\ddot{a}$ -- The thing on the left of the equation is the acceleration. To understand that, we have to understand the whole array of specifying an object’s position (coordinates) and how that position changes (derivatives, velocity, acceleration). This means (for motion in one dimension) we need the definitions of velocity and acceleration as the derivatives of position and velocity respectively.

It’s important to note that the acceleration is written on the left. We do this to remind ourselves that it’s the forces that cause the acceleration rather than the other way around. Though of course if we know the acceleration and mass we can find the net force. [Students tend to think of an equation as the way to calculate the thing on the left.]

2. $A$ -- Each of the variables has a subscript labeled by which object we are talking about. This reminds us that a fundamental assumption of the Newtonian framework is that we best understand what is happening by considering individual objects and figuring out what influences are acting on them. Each object we consider will have its own Newton 2 equation. The subscript $A$ on $F_{\text{net}}$ reminds us that it is the forces that the object feels that controls its motion. (The forces it exerts have effects on the motion of the objects it exerts them on.)

3. $F$ -- To interpret this we need to understand that it is the interactions with other objects that cause the object we are considering to change its motion (accelerate). And we need to understand how this force is quantified by an operational definition.

4. net -- This little superscript holds a lot of conceptual ideas. First, that it is the (vector) sum of the forces that an object feels that results in its acceleration. Each individual force does not produce an individual acceleration. When we break out this sum explicitly, the subscripts on the individual forces remind us that every force is caused by another object. Further, that the forces we want to include are all the forces exerted by other objects on the object we are considering.

5. $m$ -- Dividing the $\vec{F}_{\text{net}}$ by $m_A$ reminds us that the resulting force on the object is shared over the parts of the object. A bigger object will have less of a response (acceleration) to the same force.

6. $\rightarrow$ -- The little arrows on top of the acceleration and net force remind us that Newton’s second law is a vector equation. This means that each perpendicular direction has its own Newton’s law -- x, y, and z. Further, that it is the net force in the x direction that affects the motion in the x direction, the net force in the y direction that affects the motion in the y direction, etc.

That’s a lot to pack into one little equation with what looks like 3 symbols (that turn out to be 6). But each of these ideas is an essential piece of making sense of this important principle and illustrates how much complex knowledge can be represented externally in what looks like a “simple” equation.

This kind of cognitive and conceptual packing into a mathematical representation is strongly imbedded in the culture of physics, even at the introductory level. From my recent interactions in the NEXUS project, this is less common in introductory chemistry and rare in introductory biology. As a result, our biology students may not be accustomed to this kind of knowledge coding and need some explicit help to get them beyond framing equations as purely calculational tools (Tuminaro & Redish 2007; Redish 2005).
6. Conclusion

In this paper I have attempted to demonstrate the value that can be added to education research, development, and reform by taking a theoretical perspective. The overarching issues of context, cultural, representations, and their interaction show more structure when viewed in this way. And our improved understanding of this structure helps us to not oversimplify situations in which we might be first tempted to overlook their complexity at our peril.

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1 Address correspondence to: redish@umd.edu
2 Many of you can construct methods that allow you to remember all these words. This kind of thinking is what we are trying to teach our students to do! To illustrate naïve student thinking, try to do this task without using any highly developed learning skills.
3 The two test words are “needle” and “sleep”.
4 Thanks to Marjan Zadnik for this example and the reference to Johnstone’s work.
5 The “things” that can be held in working memory and manipulated may be not only single elements but “chunks” – clusters of bits of knowledge that are effectively “compiled” and can be manipulated as a single unit but later unpacked. See (Baddeley 1998; Redish 2003; and Redish & Smith 2008) for more discussion.
6 All names are gender-indicative pseudonyms.
7 The weight goes up like the cube of the scaling factor (X8), but the strength of the dowel-legs only goes up by the cross-sectional area of the dowel, which scales like the square of the scaling factor (X4).
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A Physics Teacher’s Lifetime Search for PCK and Physics Representations across Contexts and Cultures

Ed van den Berg, Free University and Hogeschool van Amsterdam, Amsterdam, Netherlands

Abstract

The challenges of physics teacher education are obvious: 1) physics teaching in schools is often uninspiring and ineffective, the many brilliant ideas for exciting physics are underused; 2) in many countries there is a shortage of qualified physics teachers, enrolments in physics teacher education are minimal, well qualified baby boomers are leaving, un- or under qualified teachers take their place, and physics teacher education has a low status in university physics departments; 3) good physics teaching needs lifelong nurture and maintenance. What can we do?

First of all, we are lucky to have a very exciting subject, let’s make use of physics excitement and put that as a first priority in our teacher education. Then there are pre-service teaching activities which can contribute much to the learning of Pedagogical Content Knowledge (PCK) and subsequent better teaching as these methods are generating PCK within the pre-service teacher’s own classroom. Six examples are described in this paper including fast feedback as an example of formative assessment which leads teaching and almost inevitably results in development of PCK. Finally some examples will be given of induction and professional development initiatives.

What is Physics Teaching? The Egg Drop as Example

In the popular egg drop activity participants try to package a fresh egg such that it can survive a drop of several meters or much more. Usually pupils and even in-service teachers work with great enthusiasm but with trial and error and no attention to the physics of decelerating and breaking objects. At the elementary school level two simple physics ideas can make a big difference: deceleration or braking distance and spreading forces. By increasing the deceleration distance or time through various kinds of packaging, the deceleration force on the egg becomes smaller. By spreading the force using packaging that touches a larger area of the egg rather than a few single points, the force at any impact point becomes smaller. At the high school level one might use the relationship \( \Delta (mv) = F \Delta t \) or \( \Delta (\frac{1}{2}mv^2) = F \Delta s \) and for a given mass and speed it is clear that the force can be reduced by increasing the deceleration time, thus the deceleration distance. I further refer to the explanations and cartoons provided in Hewitt (2011, p86-87).

These two ideas can be demonstrated in a spectacular egg throwing demonstration. Have two pupils hold up a large beach towel or other large piece of cloth and then throw an egg full force into it. It will not break unless the egg bypasses the towel and hits the wall (it happens…), or students let the egg drop after catching it in the towel. Both concepts (deceleration distance, spreading forces) are applicable across a very large range of applications: car bumpers, helmets, baseball and boxing gloves, catching basketballs, dropping glasses on carpeted versus tiled floors, etc. Two concepts which explain a very large range of everyday phenomena, that is physics! That is what our teachers should communicate and this can be done even in elementary school. In senior secondary it is possible to add another key feature of physics, quantitative modelling of the egg drop with parachutes and other types of protection. A challenge for teacher education is how to teach pre-service teachers to use such motivating and conceptual demo’s successfully.

For your next egg drop competition I propose two rounds, the first one with trial and error and then a second one after explaining deceleration distance and spreading forces. Expect better and more focussed designs in the second round! If you do not have time, skip the first round.

1 The title refers to the professional development path every physics teacher is expected to travel as well as to the personal quest of the author in a lifelong search for PCK and ways of representing Physics.
2 The author taught pre-service physics/science teacher education students in the USA (1 yr), Indonesia (10 yrs), the Netherlands (15 yrs) and the Philippines (7 yrs) and experienced in both concurrent and postgraduate physics teacher education models as well as certification courses for out-of-field teachers.
3 To avoid confusion between different types of students I use the term pupils for primary and secondary school children and reserve the term students for teacher education students.
Figure 1. The author throws an egg, Frank Schweickert and Gerda Manneveld catch it unbroken with a coat but then the egg drops on the floor (insert upper left). On the screen are the ideas “remweg” (deceleration distance) and “spreiding kracht” (spreading forces). Insert lower right: trial and error contraption by in-service teachers without awareness of the main concepts.

Challenges for Physics Teacher Education

I. Motivation. We all agree Physics is very important for society. Even high school pupils agree, but they say it is not for them. Physics is not a popular subject. This poses the first challenge, how to bridge the culture gap between physics and pupils or is it a gap between school physics (a narrowed down version of Physics) and pupils? Edgar Jenkins (2006) wrote a very interesting review of studies about the student view of science. Some of the quotes presented in his study are the following:

42% of the pupils (n = 1,432) thought that their science lessons up to the age of 16 had not made them ‘curious about the world and interested in finding out more’. (survey results of secondary pupils age 15 quoted in Jenkins 2006).

Physics, I have never, nor will I ever, see the point or understand physics. It always seemed pointless spending hours of experimental time proving what was already proven, or that black wasn’t a color, or whatever (Jenkins, 2006, p6).

From an Australian study by Leonie Rennie and colleagues, quoted by Jenkins:

The science they are taught lacks relevance to their needs and interests and fails to develop key aspects of scientific literacy. Only about one fifth of lower secondary pupils report that science lessons are relevant or useful for them, very often or almost always. About one third of these pupils indicated that science never deals with things they are concerned about or helps them make decisions about their health (quoted in Jenkins 2006, p11).

A study among 14 – 15 year olds of two different schools by one of my Master students in the Netherlands found that Physics was ranked 10 out of 18 school subjects. Not too bad, but biology was ranked 2nd. It could be worse, Mathematics was ranked 17th (Luub, 2010).
School science education can only succeed when pupils believe that the science they are being taught is of personal worth to themselves. (Reiss 2000: 156; cited in Jenkins, 2006, p1)

Such studies raise many questions about what to teach and how. Our teacher education students cannot influence what to teach, in most countries they have to teach a national curriculum and prepare their own pupils for national exams. But they can decide how to teach and that way do something about the perception of their subject. And, by the way, in my opinion science of personal worth to themselves does not necessarily exclude cosmology. The physics teacher is a travel guide who guides pupils to foreign lands to either see the familiar in new ways or see the unfamiliar but with some recognition. How can we create that kind of teacher?

II. Teacher supply, demand, recruitment. In many countries there are severe shortages of qualified physics teachers. For some countries these have been well documented such as by Vokos et al (2010) for the USA and IOP (2010) for UK. In other countries such as in Southern Europe, there may be enough teachers but there are other problems inhibiting their performance and effectiveness. For a recent discussion of teacher recruitment see Berg (2011).

III. From Novice to Professional. The first years of teaching may be the hardest compared to first years in any profession. Novice lawyers may work under the protective wings of a senior colleague. Novice teachers face their classes alone and sometimes get assigned the classes that are most difficult to handle. Many of the nice teaching methods encountered in the teacher education program, do not work yet in the first year of teaching due to classroom management problems. Novice teachers then tend to fall back to a very limited set of traditional and boring methods of teaching. Zeichner and Tabachnick already wondered in 1981 whether “the effects of university teacher education are ‘washed out’ by school experience?” Gunstone and Northfield (1994) wrote that pre-service training is, by definition, inadequate yet they also wrote (p533) that in their own teacher education alumni university training is not so much ‘washed out’ as repressed. They still adhere to the notions of learning encountered in their Dip. Ed., more so an acceptance of what is possible at this stage in their development. How can we help new teachers to grow through this novice phase and become professional teachers who can inspire, use a wide range of teaching/learning tools, and get their pupils to learn and like meaningful physics?

Models of teacher education

It is useful to distinguish between two basic models of teacher education and some variations. There are as many models of teacher education as there are countries, but most will be close to one of the following:

1. **Post-graduate model**: Students first obtain a degree (BS or MS) in Physics and then enrol in a postgraduate teacher education program including general education courses, much teacher practice in the school, and hopefully also a specialized physics education course. Usually such programs take 1 year of study, most of which is spent in practising teaching in a school. In the Netherlands most postgraduate physics teacher education students already hold a part-time teaching job which counts as their internship. This is due to the shortage of teachers in subjects like Physics, Chemistry, and Mathematics but results in insufficient guidance in the student teacher phase.

2. **Concurrent or Integrated BS Physics Education model**: students obtain a degree in physics education and study physics, physics education, and general education at the same time (concurrent) and obtain a teaching degree. In such programs it is possible to integrate physics and physics education. The teaching proposed in teaching methods courses can be and should be modelled in the Physics courses, a powerful mix! However, this mix of physics and subject pedagogy can only be realized if group size (enrolment) is sufficient to justify special courses. In two countries (Indonesia and the Philippines) and for 17 years of my professional life I have had the privilege to help develop and teach such programs.

Variations on models 1 or 2 are the following:

**Small enrolment models**: students take Physics courses along with engineering students or Physics majors and they take education courses with students from other subjects. Enrolments are so low that there are no exclusive Physics Education courses. There may or may not be science education “methods” courses
combining students from different sciences, often mainly biology or life science students. Sometimes even social science and science students are merged into one methods course, leaving no opportunities for subject specific pedagogy. The small enrolment could occur in model 1 or in model 2. In both cases it will be difficult to provide sufficient guidance for PCK development. In the USA only a handful of programs produce more than 5 physics teachers/year (Vokos et al, 2010).

**Training 2nd career teachers and out-of-field teachers:** In quite a few countries many new physics teachers are physicists and engineers who worked in industry and decided on a mid-career change towards teaching. If their subject background is sufficient, they usually join the post graduate program (model 1). If their subject background is not sufficient they first take physics courses and then join a post graduate program, or take especially tailored certification courses with a mix of subject and pedagogy (model 2).

Many suggestions for improving physics teacher education will necessarily apply only to one of these models.

**Pedagogic content knowledge (PCK): the heart of the matter**

Shulman (1986, p9-10) introduced PCK as follows:

*Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one’s subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that makes it comprehensible for others. Since there are no single most powerful forms of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice. Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that pupils of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners, because those learners are unlikely to appear before them as blank slates.*

In a special issue on PCK of the International Journal of Science Education (Berry, Loughran, Driel, 2008) Shulman is quoted about his initial research into PCK:

*Just knowing the content well was really important, just knowing general pedagogy was really important and yet when you added the two together, you didn’t get the teacher.*

This Pedagogy of Subject Matter or Pedagogical Content Knowledge was not really new in 1986. In continental Europe we already had vakdidaktiek (Dutch) or Fach Didaktik (German). In the USA there were already departments of science education in many universities and a Journal of Research in Science Teaching (since 1963) and the American Journal of Physics (since 1933). Shulman focussed on representation of subject matter such that it can be learned. Others (Magnusson et al, 1999) have extended the range of PCK to include knowledge on curriculum and exams, typical student difficulties with the subject matter, and assessment. Some main features of PCK are:

- Much PCK is craft knowledge, rooted in experience of teachers. Some is supported by research.
- Much PCK is tacit knowledge hidden in the head of the teacher and used while teaching but it is not explicit and most of it is invisible for student teachers (Loughran et al, 2008; Korthagen & Kessels, 1999).
- Some of the research generated PCK is stable and universal and likely to be valid for a long time to come such as knowledge of common preconceptions. Other knowledge might be temporary or local such as how to demonstrate magnetic fields on an OHP, how to prepare pupils best for local exams, or how to link current teenager culture to physics.
- When it does become explicit, PCK could open our eyes to teaching and learning in the classroom and therefore it could become generative: having some PCK could lead us to be much more observant and discover more PCK.
We now turn to examples of teacher education activities which not only transfer PCK to students, but have the potential to generate new PCK in the teacher’s own classroom.

**Examples of Generative PCK in Physics Teacher Education**

1. **Fun Physics as PCK generating activity**

   The first challenge for Physics Education is to motivate and create interest. Teachers have to be able to generate interest in their subject. How do you train that in a physics teacher education program? In the Philippines and in Indonesia we let our teacher education students organize exhibitions with spectacular experiments. Pre-service students organize a small exhibition in their second year and a large one in their third year. Schools are invited to visit and typically about 800 pupils from the last year of high school visit in two days. By organizing exhibitions, teacher education students explore many interesting demonstration experiments (Liem, 1991; Gluck, 2008), they learn how to present demonstrations in attractive ways, they criticize and inspire each other, and during the exhibition they have an opportunity to repeat a demo and interactive explanations many times.

   In 2011, after a 9-year absence, I had an opportunity to visit our Philippine program and collect information from over 100 of our former students who are now teachers. Many of them have their 4th year high school pupils (age 16 or 17) organize physics exhibitions as part of their physics program. Their exhibitions are targeted at lower year pupils from the same school, or parents, or sometimes elementary school pupils.

   ![Figure 2a. Using mirror’s to put a boy’s head on a girl’s body.](image)

   ![Figure 2b. A centre of mass demo with visitors.](image)

   The exhibitions have proved to be **generative** in various ways: a) pre-service students encounter many interesting demo’s and expand their stock of ideas, b) while selecting and preparing their demo they have to solve the typical hardware problems and gain confidence in hands-on, c) during the exhibition they practise interaction and explanation with visiting pupils of a wide range of abilities, and (unexpected) d) they organize their own exhibitions. School principals employing our alumni all mentioned their skills with labs and demo’s. Most physics teachers in the Philippines did not major in physics and only teach “theory”.

   Organizing an exhibition is impossible for a **small enrolment program** with less than a hand full of pre-service students, but there are alternatives. In the Netherlands we start our weekly physics/chemistry education sessions with motivating demo’s and we organize an annual demonstration competition with another teacher college. It is amazing how much extra preparation and thinking this generates in pre-service students. Another alternative is to combine several disciplines to get a critical mass of students for demo competition or exhibitions: Physics, Chemistry, Biology, Math, and Technology.
1. **Preconception interviews followed by lessons**

PCK should be generative, it should open the eyes of teacher education students so that they see more in the classroom and learn more, and so that they can ask better questions and access the tacit knowledge of mentors. An obvious and popular activity is to have pre-service students assess preconceptions of pupils using a few items of popular concept surveys such as the FCI or concept questions from Hewitt’s Conceptual Physics, or from Allen’s (2010) useful summary of alternative conceptions of elementary pupils. Results are always surprising and confront the pre-service students with the problems of concept learning.  

14 June 2012: First year students in a novel Dutch university based program for elementary teacher education presented their experiences in assessing pre-conceptions and subsequently organizing 3 lessons. They had interviewed 8 children from Kindergarten through grade 6 on topics like the moon or the water cycle (where does rain come from? Where does it go?). Then they organized three lessons for a particular grade level. They were able to pick up a range of preconceptions and original ideas of children and throughout the lessons some of the pre-service students consistently tried to follow the children’s ideas through formative assessment. Of course there was still much to be improved in the lessons, but the attention for preconceptions and embedded formative assessment is a great start in learning to teach as they are tools to make teaching generative.

Both in the Philippines and in Indonesia activities like those above really captured the interest of the pre-service students and uncovered also idiosyncratic ideas and reasoning apart from standard misconceptions reported in the literature. We as teacher educators also learned from the preconception knowledge reported by the pre-service students. The activity was generative for us as teacher educators as well as for the pre-service students. By the way, the teaching can sometimes be done in small groups of pupils to reduce disruption by classroom management problems of still inexperienced pre-service teachers.

In Indonesia and the Philippines we had a one semester course about assessment and remediation of alternative conceptions. The course turned out to be very useful and necessary to revisit school science concepts as well. In small enrollment programs and post graduate programs there is no opportunity for such a course. However, the task of assessing alternative conceptions of primary of secondary pupils is a useful one and can be executed with any number of pre-service students in large as well as small enrollment programs.

3. **Fast feedback, embedded formative assessment for pre-service and experienced teachers which generates PCK**

A more powerful way in the classroom is the use of fast feedback and peer teaching (Mazur, 1997; Berg, 2003, 2008) as it not only assesses student conceptions and other learning problems, but also remediates. In the Central Philippines class sizes ranged from 40 – 70 and averaged about 60 (figure 3). How can a teacher pay attention to individual conceptual problems in such a setting? Our answer was fast feedback. Through a series of fast paced questions with answers in the form of graphs, sketches, and diagrams and immediate plenary feedback we could diagnose conceptual problems and start remediation through plenary feedback and peer teaching. Worked out examples can be found at [http://staff.science.uva.nl/~eberg](http://staff.science.uva.nl/~eberg)

Figure 3: Gay-Ann Lapinid at the back of her class with 64 pupils

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1 In the Netherlands elementary teacher education is based in colleges, not universities. Since 2008 several universities have started university based programs.
For example, one could use the force diagram exercises of Jim Court (1999). First present some conventions about drawing forces (Berg & Huis, 1998). Show an example, and then let pupils go one-by-one through diagrams like those of figure 4. After every diagram there is a brief plenary intervention as shown in the procedures (figure 5). Obviously this graphical approach can be used in many different physics topics as documented in figure 6.

Figure 4. Examples from Jim Court’s force diagram exercises (Court, 1999). Examples of expected errors are not drawing a normal force (6), or drawing it vertical instead of perpendicular to the surface (8) and drawing a force in the direction of motion (11, 13).

Why not just give a worksheet and let the pupils do all the exercises in one go? Then with some basic misconceptions pupils may have all force diagrams wrong and leave the lesson utterly discouraged. In the fast feedback approach, presenting each problem one at a time and providing plenary feedback, gives pupils a chance to have the next one right. In this process the teacher sees real improvement happening in front of his/her eyes. Emmett et al (2009) happened to have the opportunity to twice compare the worksheet versus the fast feedback approach. In both cases they documented a series of persistent errors in the worksheet approach (all exercises in one go) while in the fast feedback approach (exercises one by one with plenary feedback after each exercise) an error would occur once or twice and then be corrected in the next exercise and pupils gained confidence.

Is the fast feedback approach just a magical bullet to erase misconceptions? No, of course not! Concept development is a slow and messy process. One might have to offer a similar exercise a few weeks or months later. Would the exercise really change student conceptions of force? Perhaps, but if not yet, at least it does increase student and teacher awareness about where they could go wrong and have to watch out.

The fast feedback approach is generative because every trial in the classroom generates some unexpected answers and makes both pupils and teachers aware of the variety of pupil ideas and reasoning. Furthermore, the teacher or pre-service student tries out new tailored explanations and examples and can immediately see the impact (or lack of it) in the next step of the exercise and try yet another way of explaining.
1. Make sure all pupils have pen and paper.
2. (Present drawing conventions if needed, perhaps an example.)
3. Present the first problem (for example figure 4a), let pupil draw the forces.
4. Go around and see 10-15 solutions in one minute.
5. Pupils will automatically start comparing solutions .... Peer teaching!
6. Perhaps squeeze in a 30-second interview about an unexpected solution.
7. Provide brief plenary feedback on the most common errors.
8. Present the next problem (for example figure 4b).

Figure 5. Procedures for fast feedback in the classroom

All physics topics offer opportunities for fast feedback (figure 6).

| Mechanics | Kinematics graphs of displacement vs time, velocity vs time, and acceleration vs time (Berg 2008), vector parallelograms, free-body force diagrams (Court, 1999); energy flow diagrams, energy system diagrams (Huis & Berg, 1993). |
| Fluid dynamics | drawing of the water surface in various liquid and pressure experiments with beakers and U-tubes, force diagrams of various objects on and in a liquid. |
| Oscillations and Waves | Plots of displacement versus time; plots of displacement versus distance from the source at different times, arrows indicating velocity and acceleration of an oscillating object at different times, force diagrams; refraction and diffraction patterns, etc. |
| Heat and Temperature | Gas laws in graphs with specific changes such as doubling the mass or the temperature: p vs V, p vs T, V vs T, diagrams, p vs V and T vs S; diagrams of cyclic processes in thermodynamics; |
| Electrostatics | charge distributions in electrostatic experiments (electrostatic induction, electroscopes, capacitors, etc.); Free body force diagrams in electrostatics. |
| Electric circuits | Indicating the relative brightness of bulbs in various parallel and series circuits, drawing A and V meters into a circuit to measure current or Voltage at/between specified points, sketching circuits with a particular function (Berg, 2008). |
| Magnetism | Drawing fields, free body diagrams with magnetic forces. |
| Electro-magnetism | Provide worksheets with pictures of coils and cores, electro motors, electromagnetic levitation devices, etc. and let pupils draw fields or forces or directions of currents. |
| Optics | Ray diagrams for shadows, flat and curved mirrors, single and double lens systems. |
| Modern Physics | Drawing atoms, crystals, potential energy versus distance graphs for various bonds with or without activation energy, at a higher level one could go into probability plots for electron orbits and other particle arrangements, plots of numbers of particles versus time for isotopes with various half-times or even for mother-daughter abundance when both mother and daughter are radioactive with long or short half-life’s. Reaction equations and simplified Feynman diagrams in elementary particles (Berg & Hoekzema, 2006). |

Figure 6. Examples of Physics Topics with Diagram or Sketch Possibilities

The fast feedback exercises can be used for different purposes:

1. To diagnose prior knowledge and skill.
2. To diagnose and remediate alternative conceptions (see force example).
3. To exercise a skill and sub-skills (graphing, axes, units, plots; use of trigonometry in physics).
4. To teach and exercise new concepts and skills in small steps (see example of elementary particle reactions and conservation laws in Berg & Hoekzema, 2005).
5. To conduct a plenary check on progress in the class after individual or small group work. For example, we are using such plenary checks in an e-learning course with mainly individual work.

WCPE 2012, Istanbul, Turkey
6. To trigger peer teaching by presenting questions which—in the teacher’s experience—lead to a variety of answers. Pupils will start to compare answers automatically.

Why is this fast feedback generative for both teachers and pre-service students? The teacher encounters “wrong” answers. Most of these correspond with popular misconceptions, but almost always there are unexpected answers. In a 30-second interview the teacher can often get an idea where it comes from. So the activity is generative in the sense that the pre-service-teacher or experienced teacher learns more about alternative conceptions and pupil thinking and reasoning. In the 30-second interview, the teacher might try a quick individual explanation while the other pupils get involved in comparing answers and peer teaching. Then the teacher goes back to the front and explains for the second time, this time for the whole class. Usually that second explanation is better than the first with the individual pupil. So the activity is generative in providing insights in pupil thinking helping the teacher to generate better explanations. Then with the next question and answers the effectiveness of the explanation can be tested immediately.

My prejudice was that pre-service teachers in the Netherlands might have a lot of trouble applying fast feedback as their classroom control is yet far from perfect. However, several pre-service teachers who still experience ups and downs in classroom management have reported positive experiences with fast feedback. Last but not least, the activity also triggers peer teaching as pupils start comparing answers and with conceptual exercises, these may be very different!

Intermezzo: More thoughts on PCK

Theory – Practice gap: PCK should be simple

In physics we opt for the theories that best fit the data. If that theory is complex, so be it. Science is not necessarily simple. Even complex theories such as those used in industrial processes to produce nano-materials, get accepted because the complex theories can be hidden in machines and software and only a few people need to understand. However, for teaching we need knowledge which translates into simple applications in the classroom. Complex theories of concept formation and remediation, or models of inquiry with too many steps, do not stand a chance in the average classroom with 30 pupils and many context variables. It is like politics and advertising and large scale reforms in business, only simple messages and slogans stand a chance of being used by typical teachers in average classrooms. However, sometimes it is possible to package complex PCK into hardware or software for teaching with a simple and usable interface.

Stability of PCK

Knowledge in science and technology is quite cumulative. An improved computer chip technology results in new processors and the old ones will gradually disappear from the market. New and bigger capacity hard drives push out the smaller capacity ones and these will not return anymore. New knowledge on climate modeling enters the models and modeling software and from then on it is used. In education that is very different. Improvements in say the teaching about energy are developed by some enthusiastic teachers/researchers and get adopted by some other teachers, and then a new textbook or a new curriculum or a new teacher might suddenly displace carefully developed subject pedagogy and gone are the gains. Nice inventions in some curriculum materials might fall by the wayside in another round of curriculum development. There is no survival of the fittest that makes it more likely that good changes stay and bad ones disappear. Good and bad educational changes have nearly equal chances to survive. This also applies to the many projects in education. Beeby (1992, p270), a former researcher, Director of Education in New Zealand in a time of reform (1940-1960), Assistant-Director General of Unesco, and educational advisor around the world, formulated it as follows:

I never cease to grieve at the tragedy of pilot projects, not the tragedy of those that fail – failures are to be expected– but the tragedy of those that succeed and then vanish into thin air.

Another point is that educational knowledge is very context dependent. New teaching methods, new lesson materials, etc., all need to be adapted to local situations. Some methods may be time- or situation-dependent and work well in a certain era or location, but not in another era or location.
As Loughran et al (2004) pointed out:

Because the need to make the tacit nature of practice explicit is not a normal expectation of being a teacher, there is a lack of a common vocabulary among teachers about teaching and learning (Kagan, 1990). Instead, teachers commonly share activities, teaching procedures, and clever insights into teaching and learning that have implicit purposes in practice, but rarely articulate the reasons behind them. Through this research project, our experience has been that asking teachers to talk about their topic-specific PCK (i.e., about why they teach particular content in a particular way) often leads to descriptions of practice that are driven by pedagogical reasons other than those most closely connected with an understanding of the content (e.g., encouraging more active learning). Hence, PCK continues to be a seductive theoretical construct but not an easily identifiable aspect of practice; consequently, there is a lack of readily available concrete examples of PCK in the literature.

So much of the knowledge of teaching is implicit in experienced teachers’ teaching – which student-teachers are rarely able to access during their practicum (Loughran et al, 2008).

4. Generating PCK through CoRe and PaP-eRs

Loughran et al (2012) worked hard at developing ways to make tacit PCK explicit. Their Content Representation (CoRe) and Pedagogical and Professional experience Repertoires (PaP-eRs) are tools to make personal PCK of teachers explicit as well as to communicate PCK to others. The content representations also make teachers think deeper about subject matter teaching by asking a series of questions about the teaching of a topic such as electric circuits (figure 7). What are the big ideas of the topic? What are the teaching/learning objectives for each idea? What will the teacher not teach about the idea? Etc. The questions are generative as they force the teacher to think much more explicitly about the teaching of a topic and provide detailed reasons for teaching rather than follow the textbook in a robot-like manner. See Loughran et al (2012) for nicely worked out examples of CoRe and PaP-eR on Particle Theory, Force, and Electric Circuits.


Studies suggest that student teachers often lack a deep conceptual understanding of the content they are supposed to teach, and that their subject matter knowledge is “fragmented, compartmentalized, and poorly organized, making it difficult to access this knowledge efficiently when teaching.”

About a topic such as electric circuits teachers are asked to formulate the big ideas in the topic and then for each of these ideas to answer the following questions:

- What is the learning objective for the idea?
- Why is it important?
- What else you know about it but will not teach?
- Learning difficulties/limitations expected from pupils.
- Knowledge about student thinking
- Other factors that influence teaching this idea
- Proposed teaching procedures and reasons.
- How will you monitor student understanding?

Figure 7. Loughran’s et al’s (2012) Content Representation
Using the tools of Loughran et al in teacher education is one of the ways to work on exactly this problem. However, pre-service teachers frame their goals for development about issues and concerns (classroom management) that are far removed from the complexities associated with thinking about or constructing PCK. They do think they master their subject and fail to recognize the poor organization of their mastery of school science.

5. **Concept cartoons to generate PCK about pre conceptions and inquiry skills of pupils**

![Figure 8. Concept cartoon](image)

Naylor and Keogh invented the concept cartoons (1997, 2006, 2011, 2012). Figure 8 shows a cartoon which can be used in two different ways:

I. Discussion: Pupils in small groups discuss the phenomenon using their prior knowledge and experiences.

II. Inquiry: Pupils design experiments to investigate the phenomenon and the claims in the cartoon.

The cartoons turn out to have a low threshold towards real inquiry in which pupils design their own experiments. They have shown to work with pupils from 8 – 18 years old. I myself have used them with children of 9 and 10 year old and they generated ideas for experiments very quickly. Their problems were in interpreting their experiments and linking evidence and conclusions (Kruit et al, 2012). Having pre-service students work with small groups of pupils could be generative as they will encounter alternative conceptions and the reasoning behind it and they will encounter typical pupil errors with regard to inquiry skills and reasoning with evidence and concepts.

6. **RTOP and other observation systems to generate PCK about inquiry teaching**

Any observation instrument will open the eyes to some new dimensions and aspects of teaching. The Reformed Teaching Observation Protocol (RTOP, 2012) is an observation instrument to observe inquiry-based teaching. It has been used widely in the USA to compare reformed with conventional teaching. Therefore training pre-service students to use this or other observation instruments might help to see more in the classroom and expand their categories for analysing teaching.
II. From Novice to Professional

The first year of teaching is probably more difficult than the first year of any other profession. Most first year teachers struggle to keep discipline in their classes. Many schools have support systems to assist new teachers. But also many schools do not and in quite a few schools new teachers are even assigned the most difficult classes to teach. Reported drop-out rates for teachers in their first five years of teaching range from 30 – 50% (USA and the Netherlands; Guarino et al, 2006; Vokos et al, 2010). Some schools have discovered that organizing support and even paying another teacher to provide regular consultation and guidance is cost effective and certainly cheaper than repeated recruitment of new teachers. Guarino et al (2006) calculated that in the USA these costs are at least $10,000 per recruitment and the authors discuss options for guidance programs for new teachers. Drop-out rates and recruitment costs are likely to vary greatly in different education systems. Nevertheless, novice teachers need support.

During a first year of teaching the novice teacher experiences classroom discipline problems which very much tend to narrow the teaching repertoire of the novice. Important meaning making activities such as POEs, conceptual discussions, and inquiry drown in the noise and chaos of the novice’s class. Many novices may conclude that the teaching methods promoted by teacher educators are not realistic and they regress to routine methods of colleagues in the school. Zeichner and Tabachnick (1981) described this regression in an article with the title: Are the effects of university teacher education ‘washed out’ by school experience? Loughran (quoted in Gunstone & Northfield 1994) states that in the case of the innovative and intense Monash University program the effects are not washed out but repressed as beginning teachers accept the limitations of their lack of experience, but stick to their ‘Monash view’ of learning in which metacognition and conceptual change are the leading concepts.

It is only after 2 or 3 years that most novices have established themselves and are ready for more sophisticated teaching methods which require good classroom control. But by then many of them have become traditional teachers. Ideally a first round of teacher education would provide survival skills for the first two years of teaching and would then be followed by another round of subject specific pedagogy as part of a professional development program or as part of a Master in Physics Education.

In our program in the Philippines we were not able to organize much support for the first year teachers. It was difficult to get them together as even on Saturdays Philippine teachers have to take part in extracurricular school activities or teacher meetings. However, we collected the novice teachers at the end of their first year and then organized a summer program in which they worked on preparation of teaching for the next school year, sharing resources and experience with each other and this way collecting their first Master credit. The Philippines does have a tradition of summer programs for teachers and does not have a tradition of family vacations. Many of them took more Master courses during evenings and subsequent Summers and eventually obtained a Master degree.

Figure 9. Professional skill development according to Ericsson (2006).
In his work on professional skill development Ericsson (2006) produced figure 9. Everyday skills are automated to make our daily life possible. Just think of the teacher who carries out many different tasks simultaneously such as managing the class, monitoring some individuals, listening to the physics of a pupil answer, etc. However, such skills can still improve through analysis and deliberate practice. When this thinking and analyzing stops, further skill development will be arrested. Perhaps this process explains the finding that there seems to be little difference in effectiveness of teachers with some years of experience as compared to teachers with many years of experience (Wingert, 2012). Only through regular analysis and practice can a professional reach and maintain an expert level of skill performance. Somehow also experienced teachers should be willing to do this and get the opportunity to do so. In our Philippine program we did this through team teaching. Two lecturers would develop or redevelop a course and teach all lessons for the course together. Post-lesson discussion would lead to much extra reflection and to deliberate practice and new ideas in following lessons.

Also experienced teachers need professional development to maintain their skills and keep developing new ideas. Rather ideal ways of involving experienced teachers is to get them into projects aimed at curriculum revision, teaching new topics, or teaching using new technology such as through e-learning. That way they can work on their professional skills in interaction with other teachers and experts in certain aspects of teaching. The direct aim of such projects is a product (new lesson materials, etc.) and professional development is an implicit objective and appears as a fringe benefit which eventually may be more lasting than the product! Yet another initiative in the Netherlands is to offer very experienced physics teachers the chance to work one day a week at a physics research facility to reconnect with academic research. A particularly attractive project is the HiSparc project in which detectors for cosmic showers have been set up on the roofs of schools throughout the country. Some teachers are assisting in the analysis of the data at the national NIKHEF center for high energy research. Teachers are also asking new physics research questions which might be worth pursuing with the detector network.

**Conclusions**

What have we learned about opportunities with respect to the challenges?

**Motivation and bridging the gap between school science culture and teenage culture:** There is a lot of “fun physics” and that is a nice way to get pupils on board. A more conceptual physics (Hewitt, 2011; Naylor & Keogh, 2011) also works well with pupils; let them argue about basic and challenging conceptual questions. There are so many tools in physics to bridge the cultural divide between pupils and school physics, but the tools are underused. Special teacher training for fun physics could include organizing exhibitions, demo competitions, and science theatre Berg (2009).

**Development of Pedagogic Content Knowledge (PCK):** Learning about physics teaching from observation in the classroom and teaching experience requires conceptual frameworks pre-service teachers often lack. However, there are teacher education activities which are *generative* and can generate the conceptual frameworks which then lead to more learning about teaching. Six examples were given in this paper: organizing exhibitions or demo competitions, diagnosing pupil ideas and reasoning, fast feedback embedded formative assessment and remediation, using concept cartoons as a trigger to designing experiments and reasoning with evidence, using Loughran et al’s Concept Representations and PaP-eRs, and using various checklists and observation instruments.

**From novice to professional teacher:** New teachers need support and assistance. Let’s use whatever means and creative ideas we have to support them. Extra guidance for new teachers is cost-effective. Also experienced physics teachers need nurture and we should involve them in our projects to provide professionally challenging opportunities. There are many more opportunities for this than we might think, be creative!

There is much for us to do to make physics lessons exciting and to recruit and train teachers who help us to disseminate the excitement and intellectual challenge of Physics. Luckily there are many tools available and many examples to follow.
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IOPblog 8 December 2010 Professional networks (to keep good teachers) http://www.iopblog.org/physics-teacher-school/


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Curriculum Development In Physics: Not Quite So Fast!

Jon Ogborn, Professor Emeritus, Institute of Education, University of London.

Abstract

The paper reconsiders some well-known problems of learning physics, in the light of recent work on the way human beings respond to problems, particularly the distinction between “fast” and “slow” thinking. It concludes that much depends on the choice of situation with which to educate “fast” thinking. This leads to a critique of recent thinking about “Inquiry Based Science Education”. The paper concludes with a discussion of problems and opportunities that currently face curriculum development in physics.

Looking back; looking forward

More than forty years ago I became involved, with Paul Black, in the development of Nuffield Advanced Physics (Ogborn 1971), a course which flourished in the UK for thirty years, and introduced many significant innovations that continue to be influential. Near the end of my career I did the same again, with the course Advancing Physics (Ogborn 2000). As we speak, there is a new movement sweeping Europe, under the banner of “Inquiry Based Science Education”, following the Rocard Report (Rocard 2007). To those of you involved in or affected by this development, and to those of you involved in other curriculum changes in Physics, I want to use this background of mine to do two things: first to offer some words of caution, and second, to sketch an agenda for future development.

Some words of caution

Habit, custom and familiarity

What I am about to say may seem very banal and obvious, but it is I think important and currently much neglected. It concerns the great importance of familiarity in making human beings feel that they understand. Roughly speaking, the rule that we all operate by much of the time is simply, “What I quickly and easily recognise is right”. Easy access to the things we know is of course an essential aspect of being able to think, but unfortunately not all the familiar things we know are relevant or right. For example:

“Mass is the quantity of matter in a body”

“Energy is what makes things happen”

Even if you are aware that these familiar phrases make little or no sense, it is still very annoying how they immediately come back to you if you have to explain mass or energy, mainly because you don’t have anything better handy.

As over the years we get used to various bits of physics, we come to think of them as much more obvious and straightforward than they are – just because they now come so easily to mind when needed. Once upon a time, Newton’s laws were as mysterious to us as they still are to our students, but having got used to them we feel that we understand, even though we may understand very little more than we once did (explain why only Newton’s Third Law is experimentally falsifiable?) This is both good and bad: good in that nobody should have to think everything out from first principles every time; bad in that one forgets what the first principles actually are; and bad in that sometimes one has got used to a not very good explanation which nevertheless stays feeling good.

Thinking, Fast and Slow

I have been led to this realisation even more strongly by recently reading the work of Daniel Kahneman and Amos Tversky, which won a Nobel prize for investigating economic decision making. Kahneman’s book “Thinking: Fast and Slow” seems to me to bring into a new focus much previous research in physics education, though that was not its intention (Kahneman 2011). He distinguishes two kinds of thinking: “Fast” and “Slow”. Fast thinking, which we all use all of the time, relies on recognising things quickly,
using associative memory triggered by context. It gets things right often enough to have great survival value, but – and it’s a big but – it isn’t always right. Worse, when it isn’t right it doesn’t much care: good enough is good enough. It doesn’t probe more deeply: “What you see is all there is”. The principle by which Fast thinking judges the correctness of an answer is simple: just by how easily it came to mind. The easier and quicker, the more convincing. No nonsense here about evidence and argument, or about being consistent. All these require Slow thinking, which takes effort and attention and is generally avoided by people whenever possible. Slow thinking analyses and compares, looks for logical consistency, considers alternatives, weighs up evidence. I’m sure that you recognise how you take a deep breath and brace yourself mentally when you confront a problem that really puzzles you. Empirically, your eye pupils dilate and your blood pressure rises. Slow thinking is hard work.

It’s also the case that Fast thinking can’t be turned off. It happens spontaneously without our willing it to do so. All we can do is consciously to try to turn Slow thinking on. With time and practice, we can train Fast thinking to throw up warning signals: “Think harder – you got this wrong before”. With long practice and much repetition, Fast thinking takes over results from Slow, so that for example skilled mathematicians instantly recognise an integral that would previously have puzzled them.

Students’ conceptions, and teachers’ conceptions too

To quote Kahneman, amongst the features of Fast thinking are that it:

- works by activating associations in memory
- infers and invents causes and intentions
- neglects ambiguity and suppresses doubt
- is biased to believe and confirm
- focuses on existing evidence and ignores absent evidence

Recall these when you next read about research on students’ conceptions (Duit 2010), or about for example the seductive power of linear causal reasoning (Rozier & Viennot 1991, Viennot 2001). Recall them also when you think about the strategies we use as teachers to create explanations that will satisfy students, giving them the feeling (maybe the illusion) that they understand. Here perhaps is one source of Laurence Viennot’s “echo-explanations” (Viennot 2010a, b).

The fact is that we spend a lot of teaching effort in trying to get students to reach answers by Fast thinking that originally depend on Slow thinking. Ultimately, that’s why rote learning can work, just by inducing familiarity so that the answer comes to mind quickly. It’s why teachers invent mnemonics, which help get the answer without thinking. It is why teachers try to think up vivid analogies or metaphors, to help Fast thinking take over.

The essential job of Slow thinking is to criticise; to consider and weigh up alternatives. Quite often it can’t be done entirely in your head: you may need pencil and paper, as well as calculator or computer. Notice that criticism is at the heart of scientific thought and, with experiment, is the basis of the robustness of scientific knowledge. Science in essence runs on Slow.

Finding a new point of view

How a topic is taught is generally the outcome of a familiar tradition, to which we become so accustomed that there seems to be no alternative, and the difficulties it gives rise to become invisible. These are what Laurence Viennot has called ‘rituals’ (Viennot 2006); they are ways that things have customarily been done, now well-learned and habitual, to which a teacher immediately turns. Any faults that they possess have, out of familiarity, become more or less invisible. Sometimes the answer is to find a fresh way to look at the problem. I will take an extremely elementary example: the principle of Archimedes. The work of the MUSE group (MUSE 2010) reminded me of this problem.
Archimedes’ principle

Traditionally, one starts in the primary school with “floating and sinking”, and children have a good time putting corks and lumps of metal into water. But then they have to be persuaded that it isn’t enough to say that “heavy things sink and light things float”, and to get involved with a discussion of density, which causes some trouble. Then one gets the magic form of words “the upthrust is equal to the weight of water displaced” and learns it by heart. Why a heavy metal boat can float often remains a mystery. The question why there is an upthrust often remains unanswered, even unasked: it is just what water does.

One day many years ago it occurred to me that this whole bit of teaching starts in the wrong place. Would it not be better to begin with what happens if you try to make a hole in water? For example, take a very light plastic cup and stand it on the water surface in a bowl. It hardly sinks in at all. Now push the cup down into the water a little – the water pushes back up. Push down some more – the water pushes back harder.

An empty plastic cup sits on the water surface.

Push the cup down to make a hole in the water. The water pushes back up

Now pour some water into the cup. When do you not need to push down any more? Just when the water inside reaches the level outside! Suddenly Archimedes’ principle becomes almost obvious.

With some water in the cup you have to push down less hard

You need not push at all when the water inside reaches the level outside
Now replace the water in the cup by a lump of metal, which is as heavy as the water, but of course smaller in volume. Then the cup will float at the same depth. What then if we made this metal into a cup of the same size? It too would float at the same level. Amazingly, the hard question the teacher usually has to answer, “How come that heavy metal boats float?” now becomes an easy question.

With a lump of metal inside, the cup can float

A heavy metal boat can also float

The whole point is the value of starting from why things happen – in this case because of the increase of pressure with depth, caused in the end by the Earth’s gravity pulling the water down so that the water below has to hold up the water above. Then Archimedes’ principle can become more than a form of words learned by heart, and floating can become something explicable.

The moral for Inquiry-based learning is that the problem you pose makes a big difference! Even extremely familiar ways are not always the best, however easily they come to mind. The job of a good introduction to a phenomenon is to set up helpful associations in students’ memories: in this case I want “pressure difference” to come to mind rather than (say) “density”. I have to admit that such challenges to familiar ways of thinking are often very annoying, just because we all rely so much on familiarity to guide us towards the appropriate.

**Inquiry-based Physics Education**

Starting from these thoughts, I turn to a critical discussion of the movement for Inquiry-Based Science Education. There is of course much to commend about it, notably its insistence on the importance of students being active in learning, and having plenty of direct experience of phenomena. I do however have some important cautions to offer.

My central concern is the impossibility of replicating the scientific process of inquiry in the frame of a typical science lesson. Scientific inquiry is inherently a very slow process, both taking a long time (years, usually) and needing the inquirer’s full critical attention. Mistakes are made, wrong paths are taken. Even if there is a sudden flash of understanding, it arises from long immersion in all the details of the problem. By contrast, the classroom requires results within a short time-frame (shall we say half an hour?). It has to rely on students’ intuitive responses, got by Fast thinking, which will most often be wrong or misguided, yet seem good to them, and be difficult to counter. As Manfred Euler (Euler 2004) put it, “You understand what you see – but you see what you understand”.

As a result, many such lessons become a kind of pretence. The teacher sets up a problem, knowing in advance what needs to emerge. What can emerge depends on the details of the problem-situation – compare for example floating corks versus “making holes in water”. The student knows this, and often feels like saying, “If only you would tell me what to discover, I will willingly do so.” In the worst case (and I have witnessed many such lessons) the practical activity becomes everything. Students try things out, perhaps write down some results, and the lesson ends – no discussion, no critical thought. The students are fairly happy, having been kept busy, and the teacher is happy, in part because no awkward questions have arisen. Of course we all know that “minds-on” matters as much as “hands-on”, but I have too often seen it prove too much to achieve.
How did well-meaning teachers ever get into relying on such parodies of inquiry based learning? The big mistake is to suppose that practical activity (“hands-on”) is the only thing that really matters. In fact, of course, to inquire is to think, and to think one must talk (and write). The task of practical activity is to provoke thought, and the teacher’s main challenge is to encourage and develop productive talk and thought. This, however, makes large demands on the teacher that they find it very difficult to meet, as many researchers have found, and which requires much special training and support (Black et al 2003). Perhaps the most difficult, and yet the most important kind of event to create in the classroom is critical dialogue, which recognises that inquiry proceeds by being critical of proposed ideas. It cannot help that essentially no examination questions ever require the student to offer a criticism, even the simplest. Such a focus on being critical is surely one of the greatest deficiencies that the movement for inquiry based learning needs urgently to face.

To stress the point, here are some of the key principles as stated in the booklet Implementing and Designing Inquiry Based Science Units from the Pollen Project (POLLEN 2009), and my brief comments on the issues they appear to ignore.

### Important principles of the inquiry-based approach

**Direct experience is at the core of learning science.**

Students need to have direct experience with the phenomena they are studying because:

- direct experience is key to conceptual understanding
- students build their understanding of the world around them, naïve or accurate, from their experiences;
- words alone often have little power to change these ideas.

**Comment:** This reads like pure naïve empiricism. Vygotski might never have existed! Instead I would say:

- direct experience is the key to making vivid and effective mental associations
- students use Fast thinking to invent plausible understandings, or to recover learned and practiced ones
- the right words, often critical ones, are needed to help students actively construct better ideas

**Comparing and contrasting with “established fact”**

As students investigate natural phenomena, they develop and compare their conclusions amongst themselves and construct new understanding. But unlike scientists, students are not discovering new phenomena and laws; rather what they learn in school is established scientific knowledge. Therefore they need to compare and contrast their work with the known by referring to other sources such as books, the internet or local scientists.

**The use of secondary sources complements direct experience.**

Students will not and cannot discover all they need to know through inquiry. The use of secondary sources in IBSE is important in the service of students’ explorations, not as a substitute for them.

**Comment:** Your ideology is really showing! How dare you put possessing established, hard-won scientific knowledge, which is the point of the whole enterprise, in scare-quotes? It is absurd that the teacher does not appear here as a source of knowledge. The reason must be a belief that it is impossible both to be authoritative and to value students thinking for themselves. I suppose that I might say instead:

To learn is to change one’s mind; to look at things in a different way. This does not come easily or quickly, especially in science where the right point of view is often unobvious, even counter-intuitive. Where students are studying phenomena in order to understand them in the scientific way, they need to be shown how easy it is to quickly come to a wrong conclusion. They need to be persuaded to try seeing things another way, and to do this often enough for the better way to become associated with the phenomenon.
The key issue here is the source of the robustness of scientific knowledge, which entitles us to teach it. It is simple: surviving all criticism so far. If we want to teach about how scientific knowledge is made, this fact has to become central. We have to require students to criticise ideas, not merely tolerate it. And they have to expect their ideas to be questioned too. The truth is that a life in science is not very comfortable, because one’s colleagues systematically doubt everything one says.

**An epistemological problem**

There is a real danger that inquiry-based learning presents scientific knowledge as “knowledge in pieces”. Planning a sequence to “establish a given concept” doesn’t really make sense, because ideas in science are strongly interdependent. That is, any new idea must not only be consistent with the evidence, but must also cohere with everything else we know. This makes it crucial to ask always about possible connections between ideas and explanations, so that science can be seen to be a coherent whole.

**Agenda for the future**

What then are some of the important things for us to try to do in developing the physics curriculum in the future?

**Resources as well as inquiries**

Despite the criticisms so far, I do believe that there is an important role for students to actively study phenomena in the laboratory, in a spirit of inquiry. But I also believe that they need to be set up in advance with the necessary intellectual resources to do so. My broad-brush picture is thus one of episodes, first of learning some background ideas (probably with lots of demonstrations too), leading to a question and to an inquiry to try to go deeper into that question (notice that I didn’t say “resolve the question”). The curriculum design problem is then to identify fruitful issues for inquiry, together with useful resources for thinking and experimenting that need to be taught first, and then to articulate these effectively together. Paul Black discusses an example of this idea, worked out in detail, in his account with Myron Atkin of their experience of science education reform (Atkin & Black 2003). It is this, too, which is a main focus of the work of the MUSE group.

**Real investigation**

I am also utterly convinced that Physics education must include an element of real, genuine investigation for students to experience. This cannot however, at the same time, be used to develop new scientific concepts (Millar 2012). The problems investigated have to be much more modest, within the student’s current grasp.

What investigation needs above all is time – time to try things out, to make mistakes, to think and think again. It also needs ownership and responsibility, so the individual student must have choice about what to investigate and how to go about it. It is worth pointing out that perhaps the most successful and lasting innovation in Physics education over the past fifty years has been the introduction of undergraduate research projects. Carefully thought out, the idea has proved workable and long-lasting in school Physics too, but only if given enough time – 10 hours is not too much for one serious investigation. Experience of doing it in *Nuffield Advanced Physics* and in *Advancing Physics* for what is now over forty years points to several key factors:

- the student must choose what to investigate
- investigations have to be kept very simple, but be given enough time
- assessment must include credit for having detected and recovered from mistakes.

**Changing the curriculum**

Reasons why it may be desirable to change the teaching of a topic in physics, or to introduce a new one include:
• The need to update the content of the physics curriculum
• The need to improve the way established topics are taught
• The need to make physics more attractive to students

Over time, perceived needs change. In the 1960s the need to update the physics curriculum was paramount; today the major concern is that students, especially girls, find physics unappealing. As a result the emphasis has shifted from what to teach, to how to teach it. Furthermore, Physics Education Research has, over the last thirty years or so, focused mainly on questions about how; about how students do or don’t come to understand important ideas in Physics, and what can be done about it.

Let me encourage you not to forget questions about what to teach, both to update the content of the curriculum and to improve the way traditional topics are presented. This often means thinking deeply about the fundamental basis of ideas, and finding good ways to represent these to students.

In wanting Physics to be attractive, we should remember the exciting new topics that find their way into popular science on television and in books. In particular, I think that you should be considering such things as:

• Digital communication, especially imaging in science and technology, from satellite navigation systems to astronomy and medicine
• The essential role now played by computational modelling both in technical design and in theorising
• Current cosmological arguments, including dark matter and dark energy
• Particle physics; why we need huge accelerators and what they can discover
• Developments in the creation of new materials, and their uses.

It is however a very awkward fact about Physics that several of its most crucial modern (and not so modern) insights seem to remain inaccessible to the school curriculum. Some of the best times of my life have been spent creating ways to teach the essential ideas of, for example, thermodynamics and quantum physics. Many others have tackled the teaching of relativity. On the agenda for the future we might place:

• Symmetry and its relationship to conservation
• The connection between spin and statistics
• The essential role of quantum phase in accounting for the existence of interactions (Ogborn & Taylor 2005).

There have been brave attempts, for example Richard Feynman’s classic book “QED: the strange theory of light and matter” (Feynman 1985), but few have been followed up.

**Making Physics attractive**

Many, many curriculum development projects (from Harvard Project Physics onwards) have set out to make Physics more appealing to young people, most recently with special emphasis on young women. Despite huge efforts and high hopes, the results have generally been disappointing, sometimes even showing a small fall over time rather than an increase. (The excuse Harvard Project Physics gave was “too much of a good thing.”) I see recently similar results coming out of the Pollen project (Jarvis et al 2009, Lindahl 2009). I think that it may even be true to say that no curriculum development project has ever achieved a major shift in the overall average of students’ liking for the subject.

This sad fact is actually not too surprising. Firstly, young people’s attitudes form quite early in life, and because they form part of their self-identity are hard to shift. Secondly, young people often actually resist attempts by older ones to please them: they prefer to please themselves, and are suspicious of well-meaning attempts to second-guess what they would like.

So what can be done? I think that one answer is honesty and pride in the value to us of Physics. An important part of this is the intellectual satisfaction of having seen how, despite difficulties, it provides models and theories of remarkable power, consistency, generality and parsimony. Overcoming the
difficulties, with help when needed, is a real part of the attraction. I quite accept that this is not a populist
recipe, though inviting students to be really critical of what they are told might be more welcome than one
expects. Indeed, one reform I would dearly like to see is classroom exercises and examination questions
giving marks for criticising flawed arguments or procedures.

The other answer is to recognise the importance of variety. There are many ways in which Physics can
appeal, not only through its power and beauty, but also through its practical understanding of how things
work. It is I believe essential to build in variety as a fundamental criterion for choosing the content and
activities for the curriculum, so as to appeal to as many different kinds of people as possible.

**Concluding thoughts**

**Slogans**

Curriculum development shares with politics the need for simple vivid slogans encapsulating its aims, just
to catch sympathetic attention and perhaps commitment.

- “Hear and forget; see and remember; do and understand”
- “Science for All”
- “Discovery Learning”
- “Ask Nature”
- “La Main à la Pâte”

Be very wary of these slogans (remember how good Mao Zedong was at creating them.) Although essential
and unavoidable to focus enthusiasm and to help people grasp the point of the activity, they rarely speak
plainly. So be very suspicious of any development project that seems to believe its own propaganda.
The reason is that in something as complex as Physics Education, there simply are no easy ‘one-shot’
solutions; there are no ‘magic bullets’. Look instead to see whether there is careful attention to practical
detail, sympathetic allowance for differences of circumstance and competence; above all, whether there
is respect for and serious involvement of the actual teachers who have to do the job.

**Pathologies**

We live in a time of widespread belief in management, technique, efficiency and targets. In the UK at
present, schools and teachers increasingly live or die by whether they reach targets, generally of student
performance in tests. This raises the stakes very high, and it is no surprise that teachers try to subvert the
system. If they can train students to pass, by whatever means, they will.

Let me put this in an even more challenging way. The job of a teacher often becomes getting students able
to counterfeit understanding. The examiners set clever questions they think will really test understanding;
the teacher tries to anticipate them and train the students to know the answer without thinking.

**Getting it all right**

Finally, I want to draw out some general messages about changing the physics curriculum, if such changes
are to have any chance at all of working in the real educational world.

First, it is essential to keep hold of the big picture, and communicate it to teachers. Teachers will never
Teach exactly as suggested, and need to be able to remember why a topic is there and what ends it serves,
to judge the way they will go about it.

Second, the devil is very much in the detail. To be effective, the teaching suggestions must really work, the
experiments suggested must be practicable, the questions provided must address the right problems and
be able to be tackled by the students. And so on. Teaching is a very practical day-to-day business, in which
a small practical hiccup can ruin a grand master plan.

Third, offer lots of teacher training. It takes time and confidence to do anything new. Indeed, as soon as
you step outside well-practiced teaching routines you tend to feel helpless, not able to answer a student’s
questions, not able to think of what to say next, etc. Taking on board a big innovation is, for a teacher, like going back to the first days in the classroom. No wonder that very often old routines are wheeled out and substituted for the new.

Fourth, and very importantly, worry about and work right from the beginning to develop the assessments to be used during and after the course. They will determine what teachers and students understand you as ‘really wanting’. In the end, the forms of assessment that you use will be decisive, and you need to be in control of them. Don’t forget to provide a lot of formative assessments for teachers to use while teaching, to tell students and teachers how well they are doing and where they need to improve. There’s lots of evidence that good formative assessment really helps learning (Black et al 2003). And do remember that generating new kinds of questions is not easy: it takes time, imagination, trial and error and hard work.

Lastly, arrange continual support for teachers, for example an email network on which teachers exchange opinions, ask for help with a confusion, tell each other where to get the latest bit of apparatus or where to find the newest internet resource, and so on. The discussions include gripes and moans, questions about fundamental physics, queries about dates for submitting coursework – in short everything, large or small, deep or trivial, that make up a teacher’s everyday concerns.

Serious curriculum change happens gradually, and so does learning. Thus, in final conclusion, a piece of advice from Paul Black and Myron Atkin (2003). It is very simple:

Make haste slowly!

References


Workgroup II - Professional Development of Teachers: Physics Pedagogical Content Knowledge (PCK) across a career

Elena Sassi, Department of Physics, University Federico II, Napoli, Italy

Introduction

For the first time at a WCPE the format of a Work-Group has been proposed. Work-Group 2 aimed at discussing the role of Pedagogical Content Knowledge (PCK) in the teaching process and its development across the teaching career.

The objectives of WG2, as presented on the Conference web-site, were:
- to reflect on the role and relevance of PCK in Physics Teacher Education (pre-service and in-service)
- to address the status of the art in the developments of PCK, also in relation with studies and proposals in Physics Education Research (PER)
- to discuss possible future activities in the framework of international cooperation
- to propose guidelines for the above identified activities

WG2 has been articulated in three sessions, each lasting 1.5 hours, to be held in different days. All participants to a WG had the opportunity to send, in advance, a contribution on paper and a short presentation during the sessions. A rapporteur, chosen amongst the participants, was asked to prepare, together with the coordinator, a report on the WG activities and a short presentation about its conclusions, to be given during the last day of WCPE.

It was also announced that: “All activities of WG2 will aim at creating a cooperative and collaborative spirit and environment; the participants are kindly invited to share this objective and contribute to its realization”.

It might be that the participants to the Conference have interpreted the WG as kind of a workshop where to find almost everything already prepared. This might explain why only one contribution has been received before the conference plus one presented at the first sessions, and a not minor turnover of people in the sessions. Twenty-five participants have worked together in the first two sessions, only seven were present at the last session.

First session

It lasted 1.5 h with twenty-five participants. The proposed theme has been recognised as a very important, vital and wide one; therefore in the first session the participants agreed to focus on aspects mainly related to Physics teaching in secondary school. Given the diverse definition of this school level in different countries it was decided to refer to the age of students (about 14 – 18 years old). Many sub-themes had been pointed out by the participants; their range was large, going from comments/questions about PCK and PER to remarks about teachers’ situations, status, conditions of work.

Here the sub-themes of the first session, not in order of priority but as they came out:
Is PCK always useful to teachers?, Few physicists teach physics, Need to explicit competences related to ICT, Inadequate pre-service and in service teachers’ education programs, State of the art of PER in each country (if and how much), Need of a National System offering resources, support, tools, … for teachers (ex. YES in NL, UK, France, Slovenia; NO in Italy, USA, Argentina, Austria), Need of bi-direction links between development of resources and PER, What should be in PCK? (Knowledge, Habits, Emotions, Curricula, Syllabuses, …), State of the art of PCK in each country, Effective Teaching and professional development of teachers depends on scale and context, the “best” teachers love teaching, the subject(s) taught, students, school, PER requires specific expertise as all other research fields, relations between Physics Education (PE) and PER, Differences between public and private schools (curricula, syllabuses, ...).
status of teachers, .....), Need of National systematic programs/projects for supporters/coaches of in-service teachers (YES in Argentina, Ch. Republic, NL, UK, France, Slovenia, South Africa; NO in Italy, USA, Mexico, Austria). Consequence of National Dogma(s) if any, Several panaceas, mainly technology-based have been proposed in last decades, Nationally curricula versus autonomous locally decisions, Physics as single discipline versus as a component of Combined Science. This last topic has finally been chosen has theme of the second session.

**Second session**

It lasted 1.5 h with twenty-five participants. The main points discussed about “Physics as single discipline versus as a component of Combined Science” can be divided in two groups: a) Physics and PCK, b) Physics teachers.

The main comments about a) have been: Physics has some characteristics as for instance “parsimony”: few fundamental theories/models, moreover the salient characteristics are different in different sciences; In the European Physical Society (EPS) Physics Education Division various ideas on this subtheme have emerged; in the Position Paper on Education (recently produced) its relevance has been recognised; In USA a National Task Force has found that very often the Physics knowledge (Subject Matter Knowledge, SMK) of Physics Teachers is inadequate, some exemplary cases of teacher education program with PCK in action, plans for programs to re-build SMK; PCK has changed much since its birth, various strategies have swept the scene (ex. Inquiry Based Science Education IBSE); Assessment types and tools as important component of PCK; PCK is additive, which PCK is worth to teach?; How do students and teachers use PCK?; Physics aims at a unified description of nature. Knowledge fragmented in pieces is not much educationally valuable; Combined Science is the best rationale, almost always it means a single course, one teacher, one mark. Economically it is convenient; What about the Subject Matter Knowledge (SMK) of the Combined Science teachers?

The b) received very much attention as it very often happens when teaching problems are addressed. The main comments about b) have been: Which types of teachers do teach Physics to 15 – 18 ys students?; Which structure do support these teachers?; Strong influence of curricula and syllabuses on the theme chosen; they are not in teachers’ hands nor the teachers have been asked to discuss how to change them; Great emphasis on curricula may became a trap when discussing the theme chosen; let’s focus on specific features of Physics with respect to Biology, Chemistry, Geology, ....; In USA some school as so small that only one teacher is available for teaching sciences; In Flanders a reform for science teaching (students about 14 – 17 ys). For Science Oriented students Physics is a single discipline; Physics is part of Integrated Science; in the Vocational stream no much Physics. 60% of Physics teachers are not physicists; In Kansas teacher licensed for Bio can become licensed in Physics by passing an exam. A two semester course can prepare them ( 2 – 3 participants); As a case of PCK in action, in The Philippines a two semesters plus 4-5 w/ends course ( 10 - 12 participants) was successful. The participants taught 4 days/weeks and were students on the w/ends; In Spain teacher education programs have 3 components: sciences, pedagogy, didactics. Most Physics teachers have a Chemistry degree; In France many Physics teachers have not a Physics degree; In Italy a University degree is requested to teach 11-18 years students. Vast majority of schools are public, their teachers are State employees. A master-like degree s requested to enter the national and regional lists of teachers; In Slovenia cross- discipline topics have been successful: several teachers discussing an interdisciplinary content.

**Third session**

It lasted 1.5 h with seven participants (same time of the GIREP Assembly). The main points to report during the final day of the Conference have been discussed. Jacqueline Spears (Centre for Science Education Kansas State University, Kansas USA) has been chosen as “rapporteur”. In synthesis: WG is a positive initiative to repeat in future, in-advance contributions are crucial.
Conclusions

The experience of WG2 indicates important improvements for having a successful such activity in the next WCPE. Two key issues are: 1) the nature of a WG has to be communicate not only via the web-site but also when the Conference starts. Possible solutions can be: to include a description of the WG in the materials given to the participants at registration, to announce the WG and its modalities in a plenary gathering of the first day of the Conference. It is important to highlight that a participation to all sessions strengths the activities of the WG and it meaning/role.

The above contents have been reported the last day of the Conference. It has been agreed that WGs are a very promising format and recommended to have them at the next WCPE.
Improving secondary students’ scientific literacy and laboratory skills: the Italian Project “Scientific Degrees”

G. Chiefari, Department of Physical Sciences, University “Federico II”, Naples, Italy
E. Sassi, Department of Physical Sciences, University “Federico II”, Naples, Italy
I. Testa, Department of Physical Sciences, University “Federico II”, Naples, Italy

Abstract

An overview of the Italian National Project “Progetto Lauree Scientifiche” (PLS, Scientific Degrees Project is presented (http://www.progettolaureescientifiche.eu/). The Project, established in 2005 by the Ministry of Education, University and Research, was initially aimed at addressing the constant decrease, since 2000, in the enrolment of secondary school students in tertiary scientific education. The involved University degrees have been: Chemistry, Mathematics, Physics, Sciences of Materials. Due to the strong focus on motivating students towards scientific-related professional careers, the Project was developed in cooperation also with the Italian National Board of Industries, to give students an informed view about employment possibilities in industrial companies. From the scientific viewpoint, the main objectives have been to: enhance knowledge of Science contents and perception about Nature of Science through laboratory activities that actively involve students; improve competences of in-service teachers on laboratory activities focusing on both contents and methodological aspects; help students become aware of their own scientific knowledge and of the pre-requisites requested to take full advantage of the University curricula; deepen special Science topics for the most motivated students. In this paper, a brief overview of the PLS Project is presented. Then, emblematic activities carried at the Naples Department of Physics are described. Finally, some conclusions are drawn.

Introduction

The “Scientific Degrees” Project (in Italian Progetto Lauree Scientifiche, PLS¹) was established in 2005 by the Italian Ministry of Education in collaboration with the Italian National Board of Industries and the Conference of Deans of the University Sciences Faculties. The main reason for starting the Project was the decrease of the secondary students’ interest and enrolment in University scientific degrees as Physics, Mathematics and Chemistry. The main aims were therefore to increase the dissemination of scientific culture in schools and to strengthen the links between University and Secondary School education by:

- enhancing the awareness of the role of Science in every-day life;
- engaging students in “hands-on” laboratories and in short research experiences at the university;
- describing concrete job opportunities given by scientific degrees.

The Project aimed also at implementing training courses for secondary school science teachers. In general the PLS activities have been articulated in three phases:

- Design: school teachers and university researchers collaborated to identify the contents of the activities to be carried out with the students
- Implementation: the activities were implemented with teachers and students;
- Dissemination: the involved teachers implemented the activities with other colleagues and other students at their school.

The Project activities have been evaluated in 2007 (Casaglia, De Luca & Sarti, 2010; Dipace & Frontini, 2010), showing a significant impact of laboratory activities on students’ views about Chemistry, Mathematics and Physics. Moreover PLS has been effective in promoting students’ awareness of the possible professional careers related to the addressed areas. A positive impact of PLS activities has been reported by teachers’

¹ www.progettolaureescientifiche.eu
interviews. Generally, the participation to the Project was considered by the teachers as an opportunity for addressing content knowledge related issues and for implementing new pedagogical methods. In 2010 the PLS has become a National Plan, and its impact is increased in terms of schools involved.

The PLS-Physics has emphasized the teaching of aspects of Nature of Science as scientific inquiry (Bybee, 2006; Krajicik et. al., 2000; Schwartz & Crawford, 2006) and mathematical modelling (Lijnse, 2008). The proposed activities were mainly laboratory experiments (lab-work), in which students could improve their competencies in data collection and analysis in order to construct a scientific model of the observed phenomena. The lab-work aimed also at improving students’ critical reasoning and argumentation skills, and at providing opportunities for self-assessment about basic physics for those students willing to enrol in a University physics degree. During the lab-work, the teachers were helped to organize and design teaching materials to be transferred in their classroom practice; the experiments being carried out both at University and schools. In the latter case, the aim was also to help in including experiments in the physics school curriculum.

In the following, the description of the PLS-Physics activities implemented in the last two years at the Department of Physics of the University of Naples “Federico II” is reported.

**ACTIVITIES OF THE PLS PHYSICS - NAPLES IN 2010-12 SCHOOL YEARS**

In 2010-11 five schools, eight teachers and about 80 students have been involved for a total of 100 hours of activities, both at school and University laboratories. In 2011-12 eight schools, ten teachers and about 107 students participated to the project, for a total of 150 hours of activities. Each school implemented the activities for about 20 hours. The laboratory experiments integrated traditional measurement apparatuses, real-time data collection and simulation tasks. Content areas addressed were: mechanics, thermal phenomena, optics, electric circuits. The organization of the activities is shown in Figure 1.

**Figure 1. Structure of the activities carried out in the PLS – Physics, 2010-11 and 2011-12**

The first activity (4h) helped the students familiarise with: scientific notation, rules for significant figures, uncertainties and their propagation, data fitting and simple mathematical modelling. The second and third activities (2 x 4 hours) have proposed two experiments chosen by the school teachers and University researchers amongst those carried out in the laboratory courses of the first two years of the Physics degree (e.g., measurement of the elastic constant of a metallic spring via oscillation period and Hooke’s law; measurement of gravity acceleration using a simple pendulum; study of the temperature vs. time trend of a hot-water mass cooling in a constant temperature environment; measurement of an unknown electric resistance). The fourth activity, at the Department of Physics, concerned the measurement of: - electron charge to mass ratio by magnetic deflection of an electrons’ beam across Lorentz’ coils, or - human hair thickness using the diffraction pattern of a laser beam. During all lab-work, students in small groups (4-5) carried out measurements and data analysis. For instance, in one activity, the students...
measured the temperature $T(t)$ of a hot water mass, initially at $T_0$, as it cools down in the environment at constant $T_a$ (Figure 2, left). The data are modelled by $\frac{T(t) - T_0}{T_0 - T_a} = e^{-\frac{t}{\tau}}, \quad \tau = 20 \text{ min}$. (Figure 2, right). In another activity, the students estimated the unknown resistance of a resistor $R_x$ using a two-resistor series circuit, given the voltage of a battery, and measuring $\Delta V_{R_1}$ across the known variable resistor $R_1$ (Figure 3, left). The circuit behaviour is modelled by $\frac{\Delta V}{\Delta V_{R_1}} = 1 + \frac{R_x}{R_1}$, (Figure 3, right).

**Figure 2.** Students at work during the PLS-Physics water cooling activity. Data analysis at right.

**Figure 3.** A student measures the voltage in the two-resistor series circuit activity. Data analysis at right.

At the end of the school year, during a workshop organized at the University, selected groups of students presented, in about ten minutes, one of the experiments carried out; all the participating students and their teachers were invited to this workshop. Finally, the involved teachers presented two seminars to other colleagues about their own experience in PLS, in order to share opinions and to propose ideas for improving students’ participation.

**EXAMPLES OF TEACHING-LEARNING SEQUENCES IMPLEMENTED IN PLS PHYSICS-NAPLES**

Here some details on emblematic activities of the PLS-Physics. These activities present a coherent teaching-learning sequence on a specific theme/context for the physics contents addressed. Methodologically the sequence is inspired by an integrated Inquiry-Based Learning and Design-Based Learning approach (Fortus et al., 2004; Puntambekar & Kolodner, 2005; Schnittka & Bell, 2010). Two addressed themes: optical fibres (emphasis on refraction and reflection law, index of refraction) and thermal insulation (Newton’s law for cooling/heating of fluids). As for the other PLS laboratory activities, a Preliminary Session (about 3 hours), was devoted to familiarise the students with the basic elements of uncertainties, significant figures, scientific notation and data fitting. Moreover, the students were introduced to some software packages used in the activities (Logger Pro, Microsoft Excel and Cabrì Géomètre).
Optical fibres

This sequence has involved 23 students at the school laboratory of a Scientific Lyceum in Naples. The lab-work has been integrated by activities with Cabri Géomètre aimed at carrying out accurate measurements and building effective descriptive models of phenomena (e.g., when a trajectory is visible and an image is produced via a digital camera) (Monroy, Lombardi & Testa, 2008; Testa & Lombardi, 2007).

In the first meeting (3 hours) after the Preliminary Session, some situations related to the use of optical fibres in telecommunications have been discussed. Then, the behaviour of fibre glass lamps, plastic rods, glass rods interacting with light was investigated in order to find out similarities and differences between optical fibres and other transparent objects that may guide the light. Then, an intriguing experiment with an illuminated water jet was performed by the students in small groups in order to discuss about how to build a light guide (Figure 4). The analysis of this experiment allowed to address the behaviour of light when it travels in homogenous materials and encounters interfaces between them.

Figure 4. Optical fibres sequence: propagation of light in a water jet

Later, the students observed the path of a laser beam in a tank half-filled with water by mean of diffusing particles. Students’ attention was focused on both the phenomena of reflection and refraction, as ways to deviate the light from a rectilinear path (Figure 5).

Figure 5. Optical fibres sequence: propagation of light in a water tank
In the second meeting (3 hours), refraction and reflection were formalised (Figures 6 and 7) through the Snell’s laws by using Cabri Géomètre. The index of refraction of an homogenous medium with respect to another was also introduced as the optical property which allows to predict the light path deviation when light hits the interface between the two media. The reflection law was introduced to quantitatively describe what happens when total reflection conditions are met. By means of a Cabri applet, the students explored light propagation in diverse media, e.g., from more to less refractive ones, and investigate the conditions under which total internal reflection occurs.

![Figure 6. Optical fibres sequence: measurement of incident and refraction angles](image)

**Figure 6.** Optical fibres sequence: measurement of incident and refraction angles

![Figure 7. Optical fibres sequence: measurement of incident and reflection angles in the case of total reflection](image)

**Figure 7.** Optical fibres sequence: measurement of incident and reflection angles in the case of total reflection

The third and final meeting (3 hours) proposed a qualitative experiment about the propagation of a laser beam in a glass tube immersed in air and in water to observe how an optical fibre is made; in particular, to clarify the need of a cladding to “protect” the fibre core, and its influence on light propagation in the fibre and acceptance angle. The regularities observed were transformed in some rules by means of Cabri simulations (Figure 8).
Figure 8: Optical fibres sequence: simulation of an optical fiber with Cabri

The proposed simulation allowed to: - introduce acceptance angle, numerical aperture and critical angle at which total internal reflection within the core occurs; - relate the numerical aperture to the refractive indices of core and cladding in a step-index optical fibre.

Thermal insulation

This teaching-learning sequence has involved 15 students at the school laboratory of a Technical Vocational School in Naples. The lab-work has used real-time measurement and temperature probes built up by the students.

In the first meeting (4 hours) after the Preliminary Session, the students in small groups (3-4), measured, first with a Hg thermometer and then with an on-line temperature probe, the change of temperature with time of water masses in a plastic cup (initial T = 60°C, left to cool down in a quasi-constant temperature laboratory, about 23°C). Each measurement lasted about 20 minutes. The students studied the collected data, modelled their trend by an exponential function, derived and compared the time constant of the cooling process in both thermometer and temperature probe experiments (Figure 9 and 10). At the end, the students related the parameters of the modelling exponential function to the physical variables of the experiment (mass of the water, heat capacity, material of the cup, heat exchange surface, etc...). Results of fit analysis for the data in Figure 9 and 10 are reported in Table 1. The values of the fit parameters in the two experiments are comparable.

Figure 9. Thermal insulation sequence: data analysis of the water cooling experiment with a thermometer.
Figure 10. Thermal insulation sequence: data analysis of the water cooling experiment with a temperature probe.

Table 1. Parameters of the water cooling modelling function $T(t) = Ae^{-Ct} + B$

<table>
<thead>
<tr>
<th></th>
<th>$A(\degree C)$</th>
<th>$B(\degree C)$</th>
<th>$C \times 10^{-5} s^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg Thermometer</td>
<td>$(20.0 \pm 0.4)$</td>
<td>$(28.9 \pm 0.4)$</td>
<td>$(62 \pm 2)$</td>
</tr>
<tr>
<td>Temperature probe</td>
<td>$(20.97 \pm 0.03)$</td>
<td>$(28.82 \pm 0.03)$</td>
<td>$(61.8 \pm 0.1)$</td>
</tr>
</tbody>
</table>

In between the first and third meeting, the students constructed, with the Electronics Systems teacher and as part of their school syllabus, three temperature sensor circuits, using the integrated component LM35C. In the second meeting (4 hours) the students addressed the problem of choosing the most suitable materials for the walls of a house so that each room could be at a constant temperature of about 22$^\circ$C when lighted up by the Sun. Each group discussed possible solutions to the problem and proposed their ideas to the whole class. After sharing the students’ proposals, it was agreed to build up a cardboard house with three “rooms”, each equipped with one of the previously constructed temperature sensor circuit.

In the third and final meeting (4 hours), the students built the agreed prototype (Figure 11 and 12) and tested it by changing the materials of the “walls” in order to keep a constant temperature in the rooms when the house was illuminated by an “artificial” Sun, i.e. a 150 W lamp.
The students drew upon the previous experiments on the cooling of water to reflect upon how the cup material influenced the temperature trend of the water. Moreover, they explored different materials and conditions to address the problem of insulation and investigated how a polystyrene “ceiling” affected the temperature of room “1” with respect to rooms “2” and “3” without ceiling. Room “2” was the farthest from the lamp, room “3” was illuminated as room “1” (Figure 13 and 14).
Figure 13. Thermal insulation sequence: test of the effect of a material. Room 1 is covered by a polystyrene “ceiling”, the others are uncovered. The “house” is illuminated by a 150 W lamp (the “Sun”).

Figure 14. Thermal insulation sequence: real-time measurements of the temperature in the three rooms of the “house” illuminated by a 150 Watt lamp (see Figure 13).

The data analysis shows that in room “2” temperature (blue data) was almost constant: $T_2 (23.02 \pm 0.09) \, ^\circ C$. Fit parameters for rooms “1” and “3” temperature are reported in Table 2. The time constant for room “1” is $(357 \pm 4) \, s$ while for room “3” it is $(111 \pm 3) \times 10^s$. The different time constants are due to the polystyrene “ceiling”.

Table 2. House heating modelling function $T(t) = A(1-e^{-ct}) + B$ (see Figure 14)

<table>
<thead>
<tr>
<th></th>
<th>$A(\circ C)$</th>
<th>$B(\circ C)$</th>
<th>$C(10^{-5} , s^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 1</td>
<td>$(5.16 \pm 0.03)$</td>
<td>$(22.26 \pm 0.04)$</td>
<td>$(280 \pm 3)$</td>
</tr>
<tr>
<td>Room 3</td>
<td>$(2.47 \pm 0.02)$</td>
<td>$(22.62 \pm 0.02)$</td>
<td>$(90 \pm 3)$</td>
</tr>
</tbody>
</table>

ACTIVITIES OF PLS PHYSICS NAPLES FOR 2012-13 SCHOOL YEAR

Three kind of activities will be proposed.

A) Laboratories aimed at improving students’ scientific literacy.

These activities, for students of the last three years of Secondary School (16-18 years), are a coherent set centred on a teaching theme. The themes will be: 1) Physics and Society, aiming at helping students acquire argumentation skills and exploit scientific knowledge in controversial “hot” situations involving...
all citizens; 2) **Physics and Technology**, aiming at helping students acquire skills related to both scientific inquiry and technological design; 3) **Real Time Physics**, aiming at acquiring basic skills for modelling natural phenomena.

More specifically, in **Physics and Society** the students, in small group, will address a controversial issue and will be gently guided, through simple experiments, to understand how to use scientific knowledge to solve the problem. Examples of controversial issues will be: global warming, nuclear waste disposal, use of renewable sources. **Physics and Technology** will propose an approach in which scientific investigation is integrated with technological design, as in the previously discussed examples, to help students understand the deep relationship between Science and Technology and hopefully gain an informed view about similarities and differences between these two areas of knowledge. In **Real Time Physics** the students will perform several experiments with on-line sensors and model simple phenomena by means of basic mathematical functions. All activities feature lab-work in small groups and will be conducted firstly at university, then at schools. Initially, for each school, one teachers with some selected students will participate to an introductory workshops (6 hours) to implement the proposed experiments. Later the teachers and students who participated to the workshop will implement the same activities in their schools, after appropriate modifications related to local constraints (if any).

**B) Laboratories to deepen general Physics topics.**

The students involved will perform laboratory experiments very similar to those made by students of first and second year of the University Physics degree. The activities will take place mainly at School laboratories. The focus will be on mathematical modelling of the observed phenomena and statistical analysis of data; the topics covered: mechanics, thermodynamics, optics and electromagnetism. The teachers will choose the experiments to be carried out in the school laboratory, according to local constraints (as the school timetable) and the initial preparation of the students. It will be also possible to perform remotely controlled experiments not easy to implement at school (http://rcl-munich.informatik.unibw-muenchen.de/).

**C) Laboratories to improve students’ self efficacy**

These five activities at the University (about 3 hours each) will be based on solving physics conceptual problems about topics of the first and second year of the University Physics degree. The activities will aim at helping the students to: be aware of their physics knowledge at the end of the secondary studies; - evaluate their motivation to undertake a university course; - increase the confidence in their preparation. Concept inventories, validated by Physics Education Research and national evaluation tests will be used. The students will also be helped to improve their argumentation skills by using PISA problems.

**CONCLUSIONS AND IMPLICATIONS**

Since 2005, the PLS project proved to be a successful framework to bridge the gap between secondary school students and university. The proposed activities have had a positive impact on students’ motivation towards scientific university courses as Chemistry, Mathematics, and Physics. The number of the schools, teachers and students involved has continuously increased through the years. Over all Italy, from 2005 until 2010, the PLS has involved 38 Universities, 3000 Schools, 4000 School Teachers and more than 30000 students. The project activities organized at the Department of Physical Sciences of Naples University “Federico II” involved about 40 schools, 60 teachers and 400 students. In 2010/2011, three activities have been carried out in the schools’ laboratories, one at the Physics Department; the aim being to help teachers in improving both their experimental competences and in using the school laboratory equipments. The teachers have proposed about half of the experiments also to different groups of students at their schools. In the 2012-13 school year, it is planned to increase the number of vocational schools involved. They have often well-furnished laboratories usable as training environments for teachers of schools with insufficient equipments or no laboratories. Moreover, the students will be offered the possibility to enhance their preparation for national and international contests (Physics Olympiads). The recent Italian secondary schools reformed physics curricula emphasize the acquisition of basic skills in investigating and modelling simple phenomena. To facilitate the achievement of this goal, Naples PLS-Physics will continue collaborating with as many school teachers as possible.
References


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Geometric Historical Approach to Investigate Celestial Bodies with a full Digital Planetarium

E. Sassi, Department of Physical Sciences, University “Federico II”, Naples, Italy
L. A. Smaldone, Department of Physical Sciences, University “Federico II”, Naples, Italy
P. Di Lorenzo, Sciences Faculty, Second University of Naples, Caserta, Italy
I. Ricchi, Caserta Planetarium, Caserta, Italy

Abstract

The educational values of activities with Digital Planetarium are increasingly acknowledged. Since 2009, the Digital Planetarium of Caserta (PdC, http://www.planetariodicaserta.it), built with support by City Municipality and EU funds Urban2, develops original activities aiming at increasing scientific competencies of students (Primary ↔ University), teachers and citizens according to active-learning strategies. At PdC the topics are discussed in an advanced multi-media ambient (the full-dome) in real-time with the help of a professional scientific tutor. Participants live an intense cognitive experience because of innovative technology and methods used. Before the PdC activities students are involved in lectures, web-search and individual study to build a basic background. Later, the didactic path continues in class by discussing observations, physical and mathematical features, critical aspects of historical methods, their success or failure and the approximations involved. In 2009 - 2012, at secondary school level, about 240 schools, 350 teachers and 11000 students have been involved. The here described “Investigating the near Space by means of Geometry” activity proposes several celebrate astronomical experiences since the Ancient Age (Eratosthenes, Aristarchus) up to Galileo (1610) and Halley (1716). Geometrical Euclidean methods are used to estimate dimensions and distances in Solar System (Earth radius, angular dimension of Sun and Moon, Moon diameter, Moon and Sun distances to the Earth, size of Moon’s mountains and distance of closer stars). For these experiences, the activity presents on the dome historical contexts, main astronomical properties of the celestial bodies involved; the original measurements are performed and compared with mathematical models. The Educational Added Value (EAV) of the activity has been tested with 42 students (17-19 years old), characterised as “expert” (extra training in Physics and Mathematics school activities) and “non-expert”, via a 45 minutes PdC session and pre-post questionnaires. The results indicate an increased specific knowledge.

Keywords: Physics and Astronomy, full digital planetarium, geometrical historical approach, students/teachers education, educational validation procedures.

Introduction

The educational activities based on working with reconstructions of the sky and celestial bodies, from catalogues of stars, pictures of planets, etc..., are becoming more and more valued (Hobson, Trubdle, & Sâckses, 2010). The analysis of these activities is useful also to reflect on the Educational Added Value (EAV) that such experiences can add to formal, non-formal and informal education at different age levels. The dynamical images (3D objects) built on the dome of a Digital Planetarium (DP) are not simulations but reconstructions from real data in an advanced multi-media environment; this very fact usually increases the motivation of the participants and helps to build or deepen their scientific knowledge. Nowadays high quality astronomical images of celestial bodies are on the web; the EAV of activities in a fully DP is much enhanced by the fact that the representation on the dome is dynamical and comes from acknowledged large databases of measured quantities. Well designed and implemented activities propose to the participant experiences that are cognitively dense because of the innovative technology as well as the methodological approaches used.

The difficulty of understanding astronomy is due in part to concepts involving geometries and orientations of celestial bodies in three dimensions. Students have to build conceptual knowledge about a three-dimensional (3D) physical space while being taught using two-dimensional (2D) textbook materials (Ku,
Evaluations of student learning in an immersive full-dome digital theatre indicate that the immersive experiences created by full-dome video enhance learning – especially of difficult concepts requiring students to change reference frames (Sumnersa, Reiffb, & Weaverc, 2008). The great potential of full-dome in teaching and learning involves relevant psychological aspects (visual perception, attention, memory, social factors and individual differences) that needs to be investigated (Schnalla, Hedgeb, & Weaverc, 2012).

In this paper the activity “Investigating the near Space by means of Geometry”, developed at the Digital Planetarium of Caserta (PdC) (http://www.planetariodicaserta.it) in 2012, by L.A. Smaldone and P. Di Lorenzo, is described as well as the reaction of forty-two students (16-19 years old) attending a secondary school.

Two research hypotheses are taken into account in the qualitative research described in the following: a) integration of Digital Planetarium (DP) activities in the syllabus of an ordinary secondary school; b) contribution of a specific DP activity to the improvement of historical, astronomical and geometrical knowledge of secondary school students.

The PdC develops original activities devoted to increase scientific capabilities in students, in-service teachers, and general public.

Up to Fall 2012, twenty-three original activities have been developed and offered; each of them is appropriate to a specific target/public, according to different level of abilities, age, knowledge, etc. The general objectives of each activity can be summarised as: - to improve the basic scientific knowledge of students and teachers through experiences based on digital representation of celestial phenomena; - to link with salient achievements in History of Physics and Astronomy; - to help in-service teachers develop deeper competences on the addressed topics; - to offer high-quality scientific edutainment to citizens of different age. The realization of an activity requires a synergic combination of different expertises and capabilities (storyboard, construction of 3D object and images from real data, relevant images selection, music selection, programming, preparation of pre/post class-work, etc...). On average more than two months of work are needed to build a forty-five minutes full-dome real-time activity.

The Italian school system is centralised, i.e. curricula and syllabuses are defined by the Ministry of Education. The vast majority of schools are State schools (e.g. 90 out of 117 schools in the Caserta Municipality area) and the teachers are State employees. Schematically: Primary school (5 years, students’ age about 6-10); First Grade Secondary School (3 years, age about 11-13); Second Grade Secondary School (5 years, age about 14-18). University education is organized according to the Bologna schema (Bachelor, Master, Ph.D.)

As far as the Primary and Secondary school level is concerned, in 2009 – 2012 about 240 schools, 350 teachers and 11000 students have been involved in the PdC activities. This impact is significant given the about 1400 schools of the Caserta Province. Many full-dome real-time activities have been up to now developed, e.g. Earth motion, Moon characteristic, Solar System, Galileo’s findings, Kepler laws, stellar evolution, orienting by means of star positions and motions, etc...; seven for the Primary school teachers and students, sixteen for the Secondary level. In all activities for the schools, active-learning strategies and approaches are used to facilitate teachers’ and students’ education (for a review on active learning in astronomy see Prather, Rudolph, & Brissend, 2009). Different levels of depth are proposed to diverse age levels.

Usually the fruition of a PdC activity is not a once-in-a-while event but part of a didactical path articulated in three phases: a) preparation in class through presentations by teachers, students’ study on books and via web-search, etc... to build a basic background for the topic to be addressed and to clarify the learning goals; b) the activity at PdC focused on representing the topic on the dome, discussing Astronomy, Physics, Mathematics aspects (almost always from different viewpoints, e.g. Earth vs Space), solving problems and using models; c) continuation in class to expand the content addressed at the Planetarium, to assess the understanding, etc...

1 The Digital Planetarium of Caserta (PdC), built in 2009 with the support of the City Municipality and EU funds Urban2, is based on In Space System, a cluster of 7 PC, 5 DLP projectors, Dolby surround 5.1, in a dome (diameter = 7 m) overlooking 42 seats. SkyExplorer allows developing the scientific / astronomical objectives in an object-oriented programming language. In Space System and SkyExplorer are trademarks of RSACosmos.

2 Currently a program for teachers-to-be is being developed.
In the following an example activity is described, the emphasis is on geometrical methods in Astronomy. The historical contents go back to Eratosthenes of Cyrene (about 275 – 195 B.C.) third librarian of the Alexandria Library, Aristarchus of Samos (about third century B.C.), Galileo Galilei (1564 – 1642), Halley (1656-1742).

The educational value/efficacy of the activity “Investigating the near Space by means of Geometry” (INV-SP-GEO) has been studied with a sample of forty-two students in the age range (16 -19).

This activity, developed in early 2012, proposes the reconstruction of several famous astronomical experiences involving geometrical Euclidean methods to estimate dimensions and distances in Solar System, e.g. Earth radius, angular dimension of Sun and Moon, Moon diameter, Moon and Sun distances to the Earth, size of Moon’s mountains and distance of closer stars. The activity aims at helping teachers and students in studying and understanding some Astronomical contents of the Italian Secondary School scientific curricula (last three years, students’ age about 16-19). The astronomical aspects and properties of the Solar System, star constellations and other celestial objects acquire tangible evidence in the dynamic representation on the dome, the learning processes are therefore facilitated. Crucial developments in astronomy and use of scientific method are addressed, together with their historical contexts and the links with conceptions and beliefs about Solar System and Universe.

The visualization from diverse reference systems (Earth, Moon, Sun, appropriate points in the Space) allows to correlate different viewpoints and to learn how to choose the most useful system according the observations to focus on and the results aimed at. Observations as well as measures are done by the participants; descriptive and interpretative models are discussed.

To frame historically the content of the activity it is useful to recall that Sun and Moon are the only two sky objects with finite dimensions at naked eye and that, around 2000 B.C., Egyptians and Babylonians had already estimated their angular dimension, from the Earth viewpoint, obtaining the same data (about 0,5°).

In the following the content of the activity is described.

Eratosthenes (around 240-230 B.C.) suggested a first geometrical method to estimate the Earth radius (Fischer, 1975). Accepting the hypothesis of a spherical Earth, he linked several pieces of astronomical knowledge experimentally based: 1) the Sun is very far from the Earth: from the geometrical viewpoint its light can be represented as parallel rays; 2) the length of shadow projected on the Earth surface by a vertical object (obelisk, column, stick, ...) changes during the day, from sunrise to sunset; 3) each day, this shadow has a (daily) minimum, at 12 a.m. local time (noon); 4) each year the shadow daily minimum is minimum in the day of Summer Solstice (June 21st in the Earth Northern Hemisphere; 5) at Summer Solstice, 12 a.m local time, there are places on Earth surface where the vertical object projects no shadow. In the hypothesis of a spherical Earth, any vertical object (e.g. an obelisk) has the direction of the Earth radius. Moreover, Eratosthenes knew that the Egyptian cities of Alexandria and Siene (now Aswan) had the same local time, namely they are on the same meridian, at a one degree approximation. Thus, in Alexandria and Siene, at Summer Solstice at 12 a.m., Sun light (i.e. rays in terms of mathematic model) illuminating an obelisk creates, respectively, a finite shadow and no shadow. Eratosthenes’s bright idea was to measure the length of the shadow in Alexandria and to compute the angle between Sun rays and the obelisk (i.e. vertical direction). The (arc) distance between Alexandria and Siene was a well known value because of the caravanned path length journey estimated time). Due to the celebrated Euclid theorem (a straight line falling on parallel straight lines makes the alternate angles equal to one another, the exterior angle equal to the interior and opposite angle, and the interior angles on the same side equal to two right angles, Euclid, The Elements, Book I, Proposition 29), the angle at the centre of the Earth is equal to the measured angle in Alexandria. Eratosthenes computed the Earth radius by the proportion: ?° / 360° = l / c, where ?° is the measured angle in Alexandria, l is the length of the arc between Alexandria and Siene and c is the length of the complete circle i.e. the local meridian (a meridian is the great circle passing through the geographic poles of the Earth and a specific location).
The method proposed by Aristarchus to estimate the radius and the distance of the Sun and Moon handles similar simple concepts of Euclidean 2D Geometry. An exhaustive and extensive description can be found in Gomez (2012). The PdC activity is then devoted to show the “renaissance” of those geometrical methods (applied in Astronomy since Egyptian and Roman ages) due to Galileo. Since the end of November 1609, Galileo studied the Moon with his 20x telescope¹ and published the results in *Sidereus Nuncius* (The Starry Messenger). He saw small dark spots, never seen before, on the illuminated part of the Moon’s surface, and small light spots in the dark area (Figure 2).

Figure 1. Eratosthenes method to estimate the Earth radius as seen in part of the planetarium dome. The realistic representation (top) and the schema (bottom). The Sun is the top-right bright spot. Due to the full-dome format (polar projection) to transfer the images from the dome spherical surface to a plane surface, there are several distortions: the solar rays do not appear straight.

As time passed, these spots varied, becoming lighter and eventually disappearing or becoming darker and more distinct. The spots “have a dark part on the side toward the Sun while on the side opposite the Sun

¹ Galileo’s first telescope was 3x, then he showed an 8x to the Doge in Venetia, later he worked with a 20x
they are crowned with brighter borders like shining ridges, as when a mountain is reached by Sun light before the valleys’. The terminator, line between light and dark, was uneven; Moon was not a perfectly smooth sphere. Moon's surface has valleys, plains and mountains as the Earth. How can the moon, a heavenly body, not be perfect and spherical? If the Moon is imperfect, could there be other imperfect heavenly bodies as well? If heavenly bodies can be imperfect, why can the Earth not be a heavenly body? Measuring the distance of the bright spots from the terminator in units of Moons’ radius, a simple application of Pythagoras' theorem provides the height of the mountain.

Figure 2. A page of Sidereus Nuncius about the determination of Moon mountains height (left); the annotations in the margin should be by Galileo (Biblioteca Nazionale Centrale di Firenze). The original Galileo’s autograph drawing of the observed effects (right).

The last interesting application of simple geometrical concept in Astronomy was provided by Edmond Halley (1716) in his famous proposal submitted to the Royal Society. He suggested to measure the solar parallax (and then the solar distance) observing the transit of Venus from two widely separated places. This has been the conjectural base for annual parallax of a star (near to the Earth) in order to measure the distance from Earth to the star (Hoskin, 1997). The first successful measurements of stellar parallax were made by Friedrich Georg Wilhelm von Struve in 1837 for the star Vega, shortly followed by Friedrich Bessel determination for the star 61 Cygni. In the INV-SP-GEO activity we propose the Sirius parallax and its distance determination.
Method

As other PdC activities, INV-SP-GEO proposes to teachers and students a full-dome real-time dynamic experience; a professional scientific tutor helps and the participants can freely interact with him/her.

The historical contexts, together with the astronomical properties of the sky bodies involved, are shown and discussed; the participants perform observations and the original measurements and compare them with the mathematical models; the geometrical proofs are proved step-by-step in a movie-like structure. Each astronomical experiment is reconstructed with a high verisimilitude with respect to the related natural phenomena, the participants’ attention and motivation is increased by the immersion into a full-dome realistic experience.

Historical images (portrait of scientists, front cover of their original books, appropriate music, recorded narration selected from historical treatises and real-time talk of the tutor, etc.) evoke the cultural atmosphere of each astronomical/geometrical experiment and aim at increasing the emotional, attentive and cultural participation of the audience. The tangible evidence of the proposed contents helps the learning and teaching processes.

The educational side is reinforced also for the general public, to feed their basic science knowledge.

As first phase of the evaluation of the education value/efficacy of INV-SP-GEO the opinions of eighty teachers of Secondary school has been analysed, after they had participated to the activity. Both contents and structure of INV-SP-GEO have been positively evaluated. Later a test with a sample of students has been conducted with forty-two students (age 17-19) divided in two groups.

The students have been selected from two different Scientific Lyceums and a Technical Institute for Building and Surveying.

Twenty-two students are so-called “naïve or no-expert” (N) students; they have no particular interest for Mathematics or other Sciences and have not participated to Olympiads or special school programs on Mathematics, Astronomy or Physics. Twenty students are so-called “expert” (E) ones who have shown specific interest for Mathematics or other Sciences and have attended some of the above mentioned programs. Due to the difficulties to select an equilibrated sample with respect to male and female (in the Italian technical school there are always much more males than females), we have no statistic elements to take into account the gender effect in the results.

The students did not know the content of INV-SP-GEO. The activity has been held in the afternoon, after the regular school program, in the middle of the week, about at the end of the school year when written tasks, recitations and assessments are due. The educational value/efficacy of INV-SP-GEO has been tested in a diverse situation with respect to the above mentioned usual protocol for schools (3 phases: pre, at PdC, post). The aim was to see how the activity improves the students’ knowledge even if they had not been previously exposed to the specific astronomical content via class-work, textbooks study, web-search, discussions with peers and teachers ...). During INV-SP-GEO, the students have answered two questionnaires, pre and post activity, in about twenty minutes for each questionnaire.

After the activity, in the whole group discussion, the most of students has expressed appreciations and positive comments. Nevertheless, several students have explicitly highlighted their difficulties in handling mathematical contents (even if already well known by them) in astronomical topics that were unknown or insufficiently understood.

The pre-activity questionnaires aimed at knowing the students’ knowledge on contents relevant to the INV-SP-GEO activity.

The post questionnaire aimed at testing the effects of the activity with respect to understanding the proposed topics and problems. The post questions are closely linked with the pre-activity ones.

The two questionnaires are reported in Appendix. The subjects of the questions are: n. 1- angular size of objects, n. 2- Earth radius estimate, n. 3 – stellar motions and parallax, n. 4 – Sun-Moon size and distance. Question n. 5, in pre- and post-questionnaires, tests the geometrical skills. In Table 1 the evaluation grid to rank the answers of each student is shown.

WCPE 2012, Istanbul, Turkey
Table 1. Evaluation grid used in assessing the INV-SP-GEO activity.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No answer.</td>
</tr>
<tr>
<td>1</td>
<td>No significant knowledge.</td>
</tr>
<tr>
<td>2</td>
<td>The student perceives the physical problem or describes it but s/he does not answer correctly.</td>
</tr>
<tr>
<td>3</td>
<td>The student roughly understands the physical problem or describes it and s/he gives an answer close to the correct one.</td>
</tr>
<tr>
<td>4</td>
<td>The student understands the physical problem, describes it and gives a correct answer.</td>
</tr>
<tr>
<td>5</td>
<td>The student deeply understands the physical problem, describes it, gives the correct answer and proposes an appropriate formal / mathematical description of the phenomenon.</td>
</tr>
</tbody>
</table>

Data and Findings

The analysis of the collected questionnaires of two groups (N = Naïve; E = Expert) is based on the:

1. response scores of each group for each question, pre versus post test;
2. cognitive gain of each group for each question (as the % of the difference pre / post);
3. % of the total correct responses of the two groups for each question, pre / post;
4. overall gain of the two groups for each item (the % difference in input and output)
5. distribution of cognitive gain for each subject in group N and group E, for each question.

Here the main results.

Question 1: angular dimension

In group N, 28% of students improve their score, increasing the values of the response codes (1 - 3 positions). Nevertheless, the total amount of appropriate and correct answers decreases from 72% to 68%. In group E, 40% of students improve their score, 45% keeping the previous one. The correct answers increase from 60% to 80%. (Fig. 3).

Figure 3. Question 1 about angular size. Difference, for each student, between the scores in pre-post-activity questionnaires. Experts (red), Naïve (blue).
Question 2: estimation of the Earth’s radius

In group N, 46% of the students improve the score (increases by 1, 2 or 3 positions), the total correct answers move from 28% to 42%. In group E, 65% of students improve the score (up to 4 positions), the correct answers increase from 30% to 60%. (Fig. 4)

Figure 4. Question 2 about Earth radius estimate. Difference, for each student, between the scores in pre-post-activity questionnaires.

Question 3: star motion and parallax.

51% of the N group students increase the score from 1 to 4; the correct answers increase from 32% to 51%. In group E, 40% of students improve the score; 20% of them keep the previous score; the number of correct answers is stable (70%) (Fig. 5).

Figure 5. Question 3 about star motion and parallax. Difference, for each student, between the scores in pre-post-activity questionnaires.
Question 4: distances Earth – Sun – Moon

Figure 6. Question 4 about distances Earth – Sun – Moon, Difference, for each student, between the scores in pre- post-activity questionnaires.

In group N, 55% of the students improve the score (increases from 1 to 4 positions). In group E, 35% of students improve scores and 45% preserves the pre-questionnaire score. The percentage of correct answers is low: - pre-questionnaire, N = 5%; E = 35%; post-questionnaire, N = 19%; E = 45% (Fig. 6).

Question 5: basic geometric background

Geometric basic knowledge differences between N and E group outgoes from the answers to Questions 5 (Fig. 6). The cumulative score of E group for appropriate abilities is 74%; the N one is 59%.

Figure 7. Question 5 on basic geometrical background. Cumulative scores in pre and post-questionnaire.
Table 2 shows the cumulative scores of good pre/post understanding astronomical topics (score ≥ 3), for the entire sample of students (N+E).

**Table 2. Good pre/post understanding (score ≥ 3) of astronomical topics in INV-SP-GEO activity.**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular dimension</td>
<td>63%</td>
<td>75%</td>
</tr>
<tr>
<td>Earth radius estimate</td>
<td>31%</td>
<td>40%</td>
</tr>
<tr>
<td>Stars motion &amp; parallax</td>
<td>50%</td>
<td>59%</td>
</tr>
<tr>
<td>Sun, Moon radius &amp; distance</td>
<td>19%</td>
<td>41%</td>
</tr>
</tbody>
</table>

**Discussion and Conclusions**

Globally, the percentage of non-response decreases and that of correct answers increases. In general, the group E seems more prudent in giving answers than N group: the percentage of non-response is higher in pre-questionnaire. In particular, the E group students probably do not seem to be able to exploit in a balanced way the time available for the test; the last Question 5 is dealt with at the end of the allotted time in both pre and post questionnaires. In N group, instead, the no-response percentage increases, in particular for Question 5. This fact may likely be explained by a cognitive task perceived as too high (such to make the student tired or discouraged to answer) and/or by a greater awareness in trying to synthesize and use the contents, acquired in the activity, in order to provide an answer. In mean, except for Question 5, the non-response percentage decreases (mean values between E and N group and pre/post results: Q1: 15% / 0%; Q2: 15% / 11%; Q3: 14% / 11%; Q4: 3% / 3%; Q5: 17% / 21%).

Questions 1 (pre and post) are focused on angular dimension, a topic rarely taught in secondary school. In the best case, it is briefly addressed in Fine Arts, when discussing the consequences related to the Renaissance perspective, but with no mathematical approach. The E group seems to recognize the link between perspective and angular size, the correct responses increasing by 20%; the N group does not.

The best performances come from Questions 2 (pre and post) on the Earth radius estimate. The school programme introduces the Eratosthenes’s method, and, probably, the students (more in E than in N) knew the content from a theoretical point of view. Then, the INV-SP-GEO allows them to gain a deep comprehension. This gain is less evident in N group.

The star motion and the parallax (Questions 3) appear to be known astronomical topics in the E group (high understanding rated to 70% both in pre and post). Likely, due to the dynamical tools used in INV-SP-GEO activity, the N group profits of this aspect and increases the response score from 32% to 51%.

The results of Questions 4 on Earth-Sun-Moon size and relative distances indicate that a high percentage of students show severe difficulties. While almost every student knows that the Moon is the satellite of the Earth, 60% of the E+N group do not extrapolate from this “dogmatic” knowledge the appropriate answer to the pre question. They are not able to transform their information into operational knowledge; the answers to the pre question are completely wrong or not significantly correct. Very likely the previous knowledge acquired at school is so “dogmatic”, resistant, common and deeply rooted that 40% of students (either E or N group) achieves an output code 1 (No significant knowledge). Globally, the percentage of correct responses (score ≥ 3) increases, but the absolute percentage of E and N groups reveals low significant effect of INV-SP-GEO.

The results seem to validate the research hypotheses:

- the integration of Digital Planetarium (DP) activities in the syllabus of an ordinary secondary school is a reliable path;
the contribution of a specific DP activity to the improvement of historical, astronomical and geometrical knowledge of secondary school students is positive.

As far as the EAV of INV-SP-GEO is concerned, both N and E groups provide similar global indications: the approaches of the activity encourage developments and improvements of the educational strategy, the specific astronomical contents and the historical framework.

The main useful didactical optimisations of the activity can be summarised as:

- to relax the density of the INV-SP-GEO contents showed in the 45' duration of the activity in PdC, to gain the participants experience a more comfortable pace;
- to address the main geometrical aspects during the class-work preparing the activity at the Planetarium;
- to include in the INV-SP-GEO storyboard a sort of “educative interface” between the usual Geometry studied in class and on textbooks and the Geometry applied to Astronomy and celestial space problems.

Acknowledgement

We are grateful to teachers and students of Liceo Scientifico “A. Diaz” in Caserta, Liceo Scientifico “N. Cortese” in Maddaloni (CE), and Istituto Tecnico “Buonarroti” in Caserta, indirizzo Geometri for their precious participation to the evaluation test.

References


Appendix

Pre-activity questionnaire to evaluate INV-SP-GEO impact

In your own words, answer the questions on the following five situations:

1. With only one eye, look at 1 euro coin located at 30 cm far from you; then at 60 cm. Describe which changes you observe:

2. Knowing the length of the Italian peninsula and having available an Earths’ image, how do you measure the Earth radius?

3. Looking at the starry night sky on June 21st and December 21st, is the apparent motion of the stars the same? For all the stars? Do the relative positions change? And if so, how? If not, why?

4. Is it nearest the Moon to the Earth or the Earth to the Sun? Always? What is the astronomical phenomenon showing that it is not necessary to go into space and observe the three heavenly bodies to answer the question?

5. Complete the following theorems (the first one, attribute to Thales is known at least since the seventeenth century B.C. in Mesopotamia).

   A beam of parallel lines intersected by two transverses determines on them ........................................

   Two parallel lines intersected by a transverse form .............

Post-activity questionnaire to evaluate INV-SP-GEO impact

In your own words, answer the questions on the following five situations:

1. This is the “Scala Regia” in the Vatican built by Gian Lorenzo Bernini, in the years 1658-1661. Why do columns at rear appear shorter? Explain.

2. You cannot measure the shadow in Alexandria at noon on the Summer Solstice but you can only do it at noon of the Spring Equinox. To estimate the dimension of the Earths’ radius, where should be measured the second shadow and what items do you need to know to perform the estimate?

3. The distance between the star Procyon and Earth is 4/3 of the distance of Earth/Sirius. Is the parallax of Sirius, with respect to Procyon one: larger / smaller / equal / not comparable (due to the different directions of two stars in space). Comparing photographs taken at six months, has moved more Sirius or Procyon with respect to distant stars? Why?

4. Why annular eclipses do also occurs (i.e. a solar eclipse in which the Moon covers all but a bright ring around the circumference of the Sun) in addition to the total solar eclipse?

5. Taken two triangles with angles $\alpha = 30^\circ$ and $\beta = 60^\circ$ degrees; if the ratio between the lengths of the two smaller sides is 2, how much is the ratio between the two major sides? How does the relationship if the angles $\alpha$ and $\beta$ are all both identical in the two triangles?
Problems Associated With the use of Multiple Representations in a High School Physics Course, Within the Traditional Context

Guillermo Neumann, MADEMS Física, Universidad Nacional Autónoma de México
Pilar Segarra, Facultad de Ciencias, Universidad Nacional Autónoma de México

Abstract

Multiple External Representations (simulations, graphs, algebraic representations, reading and writing texts) may have two principal goals in a high school physics course: the scientific literacy and the concept construction. In Mexico MER are beginning to be used, but in a context in which the teacher is the main protagonist; learning is measured by solving numerical exercises and writing reports on experimental demonstration activities (traditional context). The purpose of this study is to determine some difficulties to accomplish the goals when introducing MER in a traditional context. The exploratory and qualitative study was conducted over three semesters in a public high school at Mexico City, with three groups of 28 students from high school introductory physics. Various activities were created in which two-dimensional images, still and moving, were the center of attention together with experimental activities. The study shows difficulties for both students and teachers. In the case of students, we detect problems in data extraction, interpretation, relationship between different representations and use of concepts beyond the obvious. Teachers were faced to the problem of creating activities that simultaneously fulfill the objectives of learning and research tools; they also have difficulties integrating within a quantitative scoring system the answers given by students to the new type of activities. We found that although students recognize the importance of simulations for learning, they consider them more difficult and less valuable than traditional forms of teaching closely related to their score. To move from a traditional context to a new context, implies a transition period where inserting multiple representations does not automatically change the traditional context; the development of new materials and different teaching practice is needed. Teachers and students must accept the value of multiple representations. In this paper some activities and evaluation criteria are proposed as an approach to the goals.

1. Introduction

In the last years, different roles of multiple external representations in learning process have been studied. Some authors conclude that they can help students to construct concepts (Kress and van Leeuwen 1996, cited by Pintó, 2002) and acquire scientific literacy; nevertheless other studies (Otero) show that some contexts seem to hinder the profits. Ainsworth (2006, 2008) proposed that “the effectiveness of multiple representations can be best understood by considering three fundamental aspects of learning: the design parameters that are unique to learning with multiple representations; the functions that multiple representations serve in supporting learning and the cognitive tasks that must be undertaken by a learner interacting with multiple representations”. In traditional context these aspects are ignored, therefore there are no specific criteria for establishing clear paths for the use and evaluation of MER; the benefits and difficulties associated with their use are not well determined. We think that making explicit difficulties associated with context could be a necessary step, besides Ainswoth’s proposal, to find a way to reach the concept construction.

Among the studies that have been conducted on the use of multiple representations Aguilar et al. (Aguilar, Maturano, &Nunes, 2007) used them as a tool for detection of alternative ideas. Gilbert et al. (Gilbert, Reiner, & Nakhle, 2008) made a compilation of recent works on various topics around what is called “visualization”, emphasizing the implementation of the use of external visual representations in educational practice They suggest that to achieve the implementation of an educational innovation it must be accompanied by three basic aspects: “practical examples of the innovation must be developed, tried out in classroom, and their use evaluated”.

Otero, in her doctoral, thesis focused on how external images facilitate, hinder or inhibit the construction of appropriate mental representations to understand, explain and predict in physics, (Otero, 2002, p. 1),
while Kohl focused his doctoral work “to understand what factors influence how introductory students succeed or fail in using representations in physics” (Kohl, 2007, p. iii). Kohl defined “representations” as “different ways in which one can communicate situations and physical concepts” (PB Kohl, p. 1). Gilbert proposed that “a model may be expressed with external representations, being those versions physically available to others”. Rapp and Kurby (Rapp & Kurby, 2008, page 32.) characterized representations as analogies, simulations, ideas, concepts, or objects. For them an external representation is one that is available in the physical medium, while an internal representation is not available in it, but in the mind of the observer. Internal representations are defined as “information in memory that can be retrieved to generate students’ inferences, solve problems and make decisions “(Rapp & Kurby, 2008, p. 29).

Knight (Knight, 2008, p. 31) showed that some physical problems can be solved by an approach that requires “reasoning” with physical concepts, rather than directly apply associated equations. It is also necessary choosing the appropriate representation for a particular situation and not just following procedures that teachers should teach and students should learn. Therefore just asking the students to draw a picture is not enough. Indeed Knight goes further, stating that “a large part of learning physics is to learn how to move forward and backward between different representations of knowledge.” Gadgil et al. (Gadgil, Nokes-Malatch, & Chi, 2012) showed an application of the image as an instrument for conceptual change. Ainsworth (Ainsworth, 2008, p. 199) mentions three aspects in which the use of multiple representations may contribute to construct deeper understanding (abstraction, extension and relational understanding).

Among the most common multiple representations in physics, Gende (2008, p. 1) lists: verbal descriptions, mathematical interpretations, pictures, graphs, movement diagrams, free body diagrams, circuit diagrams, geometric optical ray tracing.

One of the problems that arise in traditional contexts is that no special activities with MER can be found. These representations are assumed to have a unique interpretation and to be directly accessible to students (self-evident), so explicit aspects of reading are omitted. These issues seem to be easily missed by teachers (Otero, Greca, & Lang da Silveira, 2003) and textbooks authors who associated properties that probably those representations do not have (Perales, 2006). The programs have excessive content and MER are not explicitly considered because one of the priorities of teachers is to finish the program (despite content understanding); so the conditions necessary for a careful analysis like Ainsworth (2008) proposed does not exist. It is supposed that this significantly limits the potential use of MERs.

To move from a traditional context to a new context implies a transition period because trying to work in a constructivist way within a traditional context seems to be contradictory and difficulties are expected.

Research questions are: What difficulties arise when multiple visual representations are used in a traditional context with the goals of attaining scientific literacy and constructing concepts in physics courses? What needs to be change in the context so that significant learning will be achieved through the use of multiple visual representations?

Although there are many meanings associated with the term “concept”, in this paper we use the definition proposed by Vergnaud (1990). He defines a concept as a triplet of three sets: the set of situations that give meaning to the concept (the reference), the set of invariants on which rests the operability of the schemes (the meaning) and the set of linguistic forms and language that can represent symbolically the concept, properties, situations and treatment procedures (the signifiers). It is not possible to debate the truth or falseness of a statement fully implicit, making it necessary to use an explicit significant for the conceptualization. There is not generally a one to one relationship between signifiers and signified, nor between invariants and situations (Vergnaud, 1990). Teachers and pupils not necessarily give the same meaning to the same external representation, for that reason visual literacy is imperative in physics. It is defined as the set of skills necessary for the individual to participate actively and critically of the visual language and visual communication, common in a techno-scientific society, establishing links between them and the conceptual, procedural and affective dimensions of physics (Neumann and Segarra, 2012).

To pay attention to the proper use of representations becomes important for both, scientific literacy and concept construction, and need to be focused during educational process. This is a basic hypothesis in this work.
Activities involving the use of visual MER were implemented, such as those applied to the reading and “writing” representations of magnetic field lines and equipotential lines in discrete electrostatic distribution. In the latter case an analogy between electrostatic field and gravitational field was proposed, willing that the isoclines lines representations serve as a bridge between the more concrete experience of the students and the relatively more abstract concept of electric equipotential lines.

2. Method

The work presented is an explanatory descriptive study based on the use of instruments for data collection. The study was conducted in a public high school in Mexico City, during three semesters, in introductory physics groups (one per semester) with 27 or 28 students each. Every group included male and female students from 15 to 18 years, with the mode in 16 years. In the second and third semesters the work was done with the same group of students, covering all topics of introductory physics courses at that level (mechanics, thermodynamics, electromagnetism and modern physics).

In the first stage, activities of pictorial representations and interpretations allusive to the experimental session were proposed to the students; they have to draw, compare images, translate between different levels of iconicity and explain their choices and performances, emphasizing in the “translation” between representations with different degrees of iconicity. At this stage no simulators were used.

In the second stage, in addition to the activities included in the first semester, problems involving pictorial association between animations and motion graphics and variable interpretation in a motion simulator were also incorporated. Roughly speaking it was sought reading and interpretation in higher levels of abstraction. Pictorial representations were also used to determine previous ideas. It included the use of simulators, but these were not part of the explicit evaluation. The first and second stages of the research were eminently exploratory and the results were published in a previous paper (Neumann and Segarra, 2012).

In the third stage two aspects were analyzed: a) the use of simulators in a systematic way as a tool to support teaching, particularly those of PhET, and b) development of criteria for evaluating the students’ external visual representations (drawings) of physical concepts. The use of MER done in this work, particularly the use of simulators, consisted in presenting the simulations in a demonstrative way (analogous to the experiments done in the course) and asking for the solution of a homework activity in order that each student practices with the simulator.

The use of simulators had also two purposes: to give students a tool that would contribute during their conceptual construction and to investigate the difficulties emerging from such use. Although some research results suggest that there is no advantage in conceptual learning with the use of simulators (Otero, 2002), our interest is based in Vergnaud approximation, which includes representations as part of the concept. In this sense, different representations could show different degrees in which a concept has been acquired.

A set of activities were created and implemented to investigate the difficulties associated with cognitive tasks involved in learning with external representations within topics of electromagnetism (electric charge, electric field, electrostatic potential, current, magnetic field and electromagnetic induction). The activities included three of the four aspects mentioned by Ainsworth (2006) about the understanding of the students using MERs: how learners understand the form of representation, how do they understand the relation between the representation and the domain and finally in what way do learners construct an appropriate representation.

Evaluation criteria were established in each case. Particularly the construction of pictorial representations criteria can be summarized by the following three aspects:

- Consider scientific representations as reference.
- To survey the syntactic and semantic elements present in scientific representations and establish with them the assessment criteria for representations made by the students.
- Consider each independently elements to perform a qualification “cumulative”, so that the approximations are qualified (seen as a process).
This article reports the results obtained in three activities. One associated to the representation of the electrostatic field, other concerning the representation of the magnetic field produced by an electromagnet and a third relating to students’ beliefs about the importance of using different representations for learning physics.

In the case of the electrostatic potential with the teaching sequence proposed was expected that the students grasp a deeper interpretation of two-dimensional graphs of equipotential lines. Simultaneously it was sought to determine some of the difficulties encountered to achieve this objective, particularly in relation to the development of the ability to translate bidimensional information (lines in the plane + numerical values representative of the potential) to a three-dimensional space (two dimensions + 1dimensión spatial scalar field).

The sequence involved creating an analogy between the lines representing isoclines in the gravitational field and equipotential lines in the electrostatic field. It was first necessary to build the concept of isocline line; students worked with three-dimensional models and then drew pictures of them in perspective. The reverse process was also used, that is, from the perspective drawings with numerical elements the students had to develop three-dimensional models. Later the students were exposed to representations of the equipotential lines of the electrostatic field due to 1 or 2 charges of the same sign or opposite sign and asked to complete a pictorial representation of the corresponding electrostatic field seen from a three dimensional perspective.

The representations of the students were classified with syntactic criteria made by comparing with scientifically accepted representation (“reference” for the assessment).

![Figure 1. Schematic representation of the sequence used for activity 2. We sought to build an analogy between isoclines and equipotential lines of the electrostatic field and then use it for reading and writing representations of electrical potential.](image)

The second activity was worked with two groups. In the first group students were asked (for homework) to use one of the Phet simulations concerning magnetic field lines due to a magnet and draw the appropriate field. The activity required that the students familiarize themselves autonomously with the simulator of physical phenomena (PhET). With the second group the work was also proposed for home, but during the next class we selected some of the representations so that students, as a group, will identify with teacher’s guidance similarities and differences between them. Afterwards, in both groups, students were asked to draw the magnetic field on a printed screen of the simulator.
For assessment of the pictorial representations made by students, criteria consisting in classifying them from the separation of syntactic elements present in the scientific representations of the same concept, were applied.

The third activity was to evaluate students’ perceptions of the usefulness of MER for learning. It was assessed with a questionnaire at the beginning and end of the course.

3. Data and findings

First Activity: Translation between two different bidimensional representations of electrostatic potential. We obtained 25 pictorial representations made by the students. These were evaluated by analyzing seven denotative elements present in the image were compared with the corresponding elements in a scientifically accepted representation. Elements considered as follows (Figure 2):

A. The representation show vertical axial symmetry.
B. The values of potential in the initial representation remain presents in the translated representation.
C. The representation is pyramidal.
D. The radio decreases as the high increases.
E. Equal increases of voltage corresponding to equal increases in high.
F. The slope increases as the radio decreases.

| A) The representation show vertical axial symmetry. | B) The values of potential in the initial representation remain presents in the translated representation. | C) The representation is pyramidal. |
| A) | B) | C) |
| ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |

D) The radio decreases as the high increases.
E) Equal increases of voltage corresponding to equal increases in high.
F) The absolute value of slope increases as the radio decreases.

Figure 2. Illustration of the criteria used in the evaluation of student’s drawings

Data: 76% of student’s drawings show vertical axial symmetry. 100% show all the numerical values presents in the initial representation. 80% of cases show pyramidal shape. In 80% of cases the radio decreases as the high increases. 36% of students do equal increases of voltage corresponding to equal increases in high. No one of the cases show the slope increasing as the distance to the charge decreases.
Figure 3. Percentage of student’s answers corresponding correctly with the accepted scientific representation in each criteria.

As a separate category was raised the presence of a representative element of the electric charge in the upper part of the figure representing the electric potential detected in 32% of cases (8/25), as shown in Figure 4.

Figure 4. Electric charge representative element present in 32% of cases.

Second activity: Representation of the magnetic field using a coil. As in the first activity criteria were established for the evaluation of the representations made by the students, based on the comparison of the elements present between them and the elements contained in a presentation scientifically accepted. The criteria used were as follows:

1.1 Drawing show lines or something representative of electromagnetic field.
1.2a Field lines are continue lines.
1.2b Field lines show a close path.
1.3a Symmetry 1: Field lines are presents in both sides of the solenoid.
1.3b Symmetry 2: Field lines are present in equal number in both sides of the solenoid.
1.3c Symmetry 3: Field lines have the same size in both sides of the solenoid.
1.4 Two or more lines are present and don’t intersecting one to each other.
1.5 Shape of individual field lines is qualitatively correct.
1.6 Magnetic field lines seem to go out from the inner of the solenoid.
1.7 Applies the selection of north and south poles of the electromagnet in the direction of the field created by the current of the battery.
1.8 It is associated with direction field lines.
1.9 The direction of the field lines going from North Pole to South Pole whether they are explicit or possibly corresponding to the current that generates according to the right-hand rule.

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Since we worked with two different groups, the activity has at least two aspects to contemplate, first the results for each group separately and on the other to compare these results.

Figure 5. Example of representation of magnetic field showing lack on 1.4 criterion; the magnetic field lines are intersecting one to each other.

The graph below summarizes the results obtained in each of the groups (Fig. 6):

![Graph showing comparison between magnetic field representations with and without previous activity to state explicitly the elements in the representation.]

Figure 6. Comparison between magnetic field representations with and without previous activity to state explicitly the elements in the representation.

As a complementary activity students were asked to explain in written form the pictorial representation of the field produced by the electromagnet. 54% (12/22) of the students showed confusion between magnetic poles and electric charges (or voltages in a battery). This confusion can be detected both through drawings and through the text. Examples of this type of confusion are the following statements:

• "The attraction and the current direction is always north-south"
• "When the current circulates through the coil generates a magnetic and electromagnetic field which causes current to leave the North Pole and South Pole arrives, going from + to -"
• "Because the magnet has the south pole on the negative side of the battery will cause charges repel each other because like charges repel, so no power."
• "What happens is that forms an electromagnet from south to north as the battery on the right has a positive value."

Third activity: Two questionnaires were proposed. The first was designed to classify the degree of utility perception that students associated with different types of representations to support learning in physics with closed answers. This questionnaire required the categorization into five levels (Not Useful = 1; Useful = 5) and was applied at the beginning and end of the course. The data obtained are shown in the following graphs (Fig. 7 and 8).
The second questionnaire, proposed at the end of the course, asked to evaluate the use of images and simulators for the course through four open-response questions.

Among the positive answers: 75% (18/24) of the students stated that the use of images and simulators help them to understand in general terms, 54% (13/24) indicated that helps them to understand the class or theoretical concepts while 50 % said that helps them to understand the world, reality or physical phenomena, 25% (6/24) stated that enables them to view, observe or see, without explicitly mentioning that help or facilitate the work. Regarding the negative answers: 75% (18/24) said that simulators are difficult to understand (difficult, confusing or complex), 16% (4/25) mentioned that they are tedious or boring.

As proposals for improving the use of such representations: 58% (14/24) referred to their desire that the teacher explains the simulations (prior to the activities performed), 33% (8/24) request lower participation of some of its peers because “confused them”. It is noteworthy that 30% (7/24) did not answer or said they did not change anything.

4. Discussion and conclusions

Three major groups of interrelated difficulties seem to emerge when trying to use multiple representations in a traditional course: those related with epistemological beliefs of students and teachers, those associated with the creation and implementation of activities which exploit the potential of the multiple representations for conceptual development and scientific literacy and finally the development of appropriate assessment involved in establishing the use of such representations.
A) Difficulties associated with epistemological beliefs and the use of MER.

First of all it can be seen that in a traditional course epistemological beliefs of students and teachers make that representations considered most useful are those that have been considered traditionally important. The results of the survey conducted at the beginning of the semester (fig. 7) show that students considered most useful for learning physics solving numerical problem, experimental demonstrations and lectures. This fact is emphasized by grouping the data into two categories: activities to which students have been exposed for several years in a traditional context and the use of uncommon activities for them in class (use of simulators and image literacy), as shown in the following graphs (Fig. 9).

![Initial evaluation](chart1.png) ![Final evaluation](chart2.png)

**Figure 9.** Perceived usefulness of different types of activities at the beginning and end of the course

In the initial evaluation the types of activities considered most useful by the students agree with those included in traditional assessments. While comparing both distributions there are changes in the answers, it may be noticed an increase in the perception of the usefulness of simulators and images, we think that this does not mean that students have profoundly changed their beliefs. Instead, it seems more likely to interpret survey results as an adaptation to the new proposal.

This would mean that students have maintained the prevalent idea in traditional contexts, what is “useful” is what serves to meet the assessment criteria, rather than a reflection on the learning process. The suspicion of an interpretation of the results in this sense is based on some of the answers given in the open responses survey as the superficiality with which the representations have been used.

In the first case, although a high percentage of students suggests that the use of images and simulations during the course “helps them to understand”, only 40% (11/27) carried out the homework including the simulator. 58% (14/24) spoke of their wish that the teacher explains the simulations and 33% asked their peers not to participate, which corresponds to the traditional view that it is the teacher who must “give” the “right” answer. The rooted idea in teachers and students, that the concepts are transmitted via retention seems to persist also in relation to the use given to other types of non-traditional representations. Students undertook an explicit activity of the visual elements present in the simulator and obtained a better approximation to the accepted scientific representation, but they were not able to explain the physical reasons associated with the assessment criteria. For example, although the magnetic field representations were significantly better in symmetry aspects and not intersecting field lines (categories 1.3a, 1.3b, 1.3cy 1.4), students were unable to explain the reason why the lines should be symmetrical and why should not intersect; 54% of students had misunderstanding between magnetic fields, voltage and electric charges. Added to this is the fact that none of the students during class uttered concern over the physical reason of the restrictions imposed on the representation. It seems that we are going form memorizing algebraic algorithms to memorizing a visual representation, accepted uncritically and without profound meaning.
**B) Difficulties associated with the creation and implementation of activities to exploit the potential of the MER.**

The reflection on this point arises not only from the answers given by the students to the activities to which they were exposed, but the reflection on the process of creation of such activities. Bringing new representations to traditional contexts hoping to connect the potential of the MER implies a change in the activities carried out and the time devoted to them, involves raising new goals, develop new skills and procedures of evaluating and changing the values in both learners and teachers.

In a traditional context there are no activities to work these issues through the use of multiple representations, which mean they must be developed by the teachers themselves. The activities and the objectives to accomplish seem not to be clear in advance, but must be constructed through a process of evolution. Therefore the activity proposed for the development of reading and writing of the equipotential lines and the criteria used for the analysis of the answers given by the students in each activity are only a first approximation. The context itself made the activities and criteria to be closer to the description of the elements present in the representations than to the development and analysis of the issues raised by Ainsworth (2008).

Proposed activities sought to establish interconnection to specific situations, but it seems that students were unable to overcome the descriptive level. For example, the case of the equipotential lines included experiments, simulations and work with models for the development of the concept of isoclines lines, which in turn is supposed a basic pictorial representation and interpretation of the gravitational potential. Once the students had achieved abstraction in the case of isoclines raised the analogy with the equipotential of the electrostatic field, with the idea of transferring that knowledge to the representation of the electric field (via extension), however 32% of potential representations explicitly included a representation of the electric charge in the area corresponding to the highest potential, suggesting that at least these students remained in the most concrete level, similar to what happens with students who interpret a negative slope in a position versus time graph like a “down” space.

Nevertheless the results shown in the figure 1, arises the question whether the fact that you can make a representation closer to the scientific reference, even with a superficial understanding of it, should be considered or not a better approach to the concept. It seems that, considering the physical concepts as more general (perhaps closer to the proposal of DiSessa or Vergnaud), where representations and associated situations are part of the concept itself, we should accept that there is indeed further alignment to scientific concept when improving the representation, although it is only a small step toward the desired conceptualization.

**C) Difficulties associated with evaluation**

In traditional courses there are representations that are more appreciated than others, because they are considered closer to what students should learn. Some external representations, like images, are considered self-evident and of relative low value. Thus, in many cases, the algebraic representations (such as equations) are preferred to drawings. Consequently the evaluation focuses more on algorithmic use of equations. When drawings become present there is often no explicit evaluation criteria (if evaluated at all), or the criteria used is “all or nothing” there are not midpoints. Even seeing that it is desirable that the representations of students approximate to scientific representations, from a constructivist position it should be considered different levels of approximation to the answer and assessment should contemplate these levels from what the student does, not from what the student cannot do. In this sense the proposal of Vergnaud seems relevant to establish graded evaluation criteria.

In the case of the activity with equipotential lines, students should translate the information present in a two dimensional graphical representation to a flat representation in perspective of a three-dimensional space of the electrostatic field. This activity can also be understood from different levels, covering the superficial and the deeper visual aspects, such as whether or not to explain the limits of the analogy. The evaluation of both aspects is necessary to establish the level of conceptual development; it is just a small part of the triplet proposed by Vergnaud.
D) Conclusions

By raising the use of MER in a traditional context we find a number of difficulties, including both students and the teacher. The main difficulties encountered are set in three different ways:

- Epistemological beliefs of students and teachers, through the deeply rooted traditional school setting appear to be difficult to overcome. These include the role to be played by teachers and students, assessment schemes for different types of activities, and how they are used in different types of representations that are used during the course.

- To take advantage of the MER efficiently and deeply, we need to develop the skills that are associated with them. Because students have little visual literacy in physics, the first steps seem to be quite slow, and requires careful advance. It would be desirable to detect all the time what students cannot do with each kind of representation, however this requires both specific activities as the time needed to produce, implement and evaluate them. Likewise, we should ask about the relevance of refocusing the course objectives towards skills development (such as those associated with the literacy skills of the image), even at the expense of the skills traditionally associated with learning physics (skills for solving exercises and quantitative problems, whether they are associated with management skills or to numerical measurement techniques).

- The evaluation of pictorial representations made by students requires hard work from the teacher, which includes selecting the elements to evaluate, creating categories and evaluation criteria and the application of them in each of the individual tests. This requires time and skills beyond those of many teachers immersed in the traditional context.

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Así mismo, al final del curso la percepción de los alumnos sobre la utilidad de los diferentes tipos de actividades pareció modificarse, incrementándose el valor que asociaban con el uso de actividades relacionadas con simulaciones e imágenes. Este resultado debe ser tomado con reserva, pues pensamos que esa utilidad se asocia directamente al hecho de que las simulaciones e imágenes asaron a formar parte de los exámenes y no porque los alumnos logren profundizar en la utilidad de las RM para el aprendizaje en sí mismo.

**Conclusiones:**

Al plantear el uso de RM en un contexto tradicional encontramos una serie de dificultades que incluyen tanto a los alumnos como al profesor. Las dificultades principales encontradas se establecen en tres aspectos diferentes:

- Las creencias epistemológicas de alumnos y maestros, profundamente arraigadas a través del contexto escolar tradicional parecen ser difíciles de superar. Entre ellas se incluye el papel que deben jugar maestros y alumnos, los esquemas de valoración de los diferentes tipos de actividades, y la forma en que son utilizados los diferentes tipos de representaciones que se usan durante el curso.

- Para que las RM se logren aprovechar de manera eficiente y profunda, se requiere del desarrollo de las habilidades que se asocian a ellas. Debido a que los alumnos tienen una escasa alfabetización visual en física, los primeros pasos parecen ser bastante lentos, y requiere de un cuidadoso avance. Sería deseable detectar a cada momento lo que los alumnos pueden o no hacer con cada clase de representación, sin embargo esto requiere tanto de actividades específicas como de los tiempos necesarios para producirlas, implementarlas y evaluarlas. Así mismo, habría que preguntarse sobre la pertinencia de reenfocar los objetivos del curso hacia el desarrollo de competencias (como las asociadas a las habilidades de lecto-escritura de la imagen), aún a costa de las habilidades tradicionalmente asociadas al aprendizaje de la física (como las habilidades para la resolución de ejercicios y problemas cuantitativos, ya sean estos asociados a las competencias de manejo numérico o a las técnicas de medición)

- La evaluación de las representaciones pictóricas hechas por los alumnos requiere un arduo trabajo por parte del maestro, que incluye la selección los elementos a evaluar, la creación de categorías y criterios de evaluación y la aplicación de ellos en cada uno de los exámenes individuales. Ello requiere tiempo y habilidades ajenas a muchos profesores inmersos en el contexto tradicional.

WCPE 2012, Istanbul, Turkey
• una de las cosas que es necesario cambiar para lograr un mejor uso de las RM, es la valoración que los alumnos (y profesores) hacen de las diferentes actividades, un “cambio epistémico”, donde el uso de las representaciones múltiples sea visto y aprovechado como una herramienta para coadyuvar en el proceso enseñanza-aprendizaje de la física, pero también como la posibilidad de desarrollar habilidades útiles para toda la vida (elementos de la alfabetización visual).

Appendix 1

<table>
<thead>
<tr>
<th>CRITERIOS PARA EVALUAR LAS RESPUESTAS A LA PREGUNTA 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Se dibujaron líneas o algo que representa el campo, sea o no una representación correcta</td>
</tr>
<tr>
<td>1.2 a Las líneas de campo son continuas.</td>
</tr>
<tr>
<td>1.2 b Las líneas de campo muestran un camino cerrado</td>
</tr>
<tr>
<td>1.3 a Simetría 1: Se presentan líneas de campo en ambas direcciones de la bobina</td>
</tr>
<tr>
<td>1.3 b Simetría 2: Se dibuja un mismo número de líneas a ambos lados de la bobina.</td>
</tr>
<tr>
<td>1.3 c Simetría 3: Las líneas a ambos lados de la bobina son del mismo tamaño.</td>
</tr>
<tr>
<td>1.4 Se muestran dos o más líneas de campo y no se intersectan entre sí</td>
</tr>
<tr>
<td>1.5 La forma de las líneas de campo individuales es cualitativamente correcta</td>
</tr>
<tr>
<td>1.6 Las líneas “nacen” del eje de la bobina. (Se asocia explícita o implícitamente un polo Norte y un polo Sur a la bobina del electroimán en el eje axial de éste último)</td>
</tr>
<tr>
<td>1.7 Corresponde la selección de los polos Norte y Sur del electroimán con la dirección del campo creado por la corriente de la pila</td>
</tr>
<tr>
<td>1.8 Se asocia dirección a las líneas de campo</td>
</tr>
<tr>
<td>1.9 La dirección de las líneas de campo va del polo norte al polo sur ya sea que éstos sean explícitos o en su caso que correspondan a la corriente que los genera según la regla de la mano derecha.</td>
</tr>
</tbody>
</table>

Criterios similares fueron propuestos y aplicados a cada pregunta de los exámenes realizados durante el semestre. La determinación de dichos criterios para cada uno de los casos específicos fue una de las dificultades que se presentaron, tanto por la falta de antecedentes que teníamos en ese tipo de evaluación como por los tiempos requeridos para la revisión de las respuestas obtenidas.
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Dismantling Rainbow

F. Favale, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, Como, Italy
M. Bondani, Istituto di Fotonica e Nanotecnologie – CNR, Como, Italy, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, Como, Italy

Abstract

We present a didactic route to the learning of elementary optics starting from the observation of the rainbow. The basic idea is to start from the bare observation of the natural phenomenon and to guide students to the discovery of every single optical process governing it.

We want to reverse the learning process so that the explanation of the single optical processes included in a standard optics curriculum for High Schools will naturally emerge as a demand for understanding the main phenomenon, the rainbow. At the end of the course the students should at least reach the same content knowledge level achieved by traditional teaching, but with greater satisfaction. The “dismantling” of the rainbow takes advantage of the indoor reproduction of the rainbow by using either a glass sphere (raindrop) and a white-light projector (sun) or cylinders of transparent materials (glass, plexiglas, glycerol) and beams of collimated white light beam or lasers at different wavelengths. The quantitative analysis of the experiments is carried on by taking pictures/movies of the setup and analyzing them with a free analysis software like Tracker Video.

Keywords: Rainbow, fundamental optics, atmospheric optics, secondary education

1. Introduction

The observation of natural phenomena is the most obvious starting point of the scientific approach to knowledge. In spite of this trivial remark, we observe that, at least in Italy, the large part of school lessons is held in the form of frontal lectures, in which teachers propose a defined set of information following a standard lesson plan. In this framework, the direct observation of phenomena is usually inserted as examples to confirm theory.

We present a didactic route to the learning of elementary optics starting from the rainbow that reproduces the different steps of the scientific method. The basic idea is to start from the bare observation of the natural phenomenon and to lead students to the discovery and the physical interpretation of every single optical process governing it.

The idea to focus on rainbow as a useful example for teaching optics is not new (Sakurada 2002, Isik 2012, Hendry 2003, Russell 1989, Premio Bonacini 2007), but in most of the proposed paths, the discussion of the phenomenon is used to summarize the concepts of standard geometrical optics courses (reflection, refraction, dispersion, vision...) at the end of a standard course. At variance with them, we want to reverse the learning process so that the explanation of each single optical process included in a standard optics curriculum for High Schools will emerge naturally as a demand for understanding a phenomenon, the rainbow, which is the goal of the entire activity. This reverse path is actually the straight one if we think at the scientific method protocol: observation and data collection come first and predictive law application are at the very end of the study.

From the didactic point of view, at the end of the activity students should at least reach the same content knowledge level achieved by traditional teaching, but hopefully with greater satisfaction and personal involvement.

The “dismantling” of the rainbow takes advantage of the indoor reproduction of the natural phenomenon by using a glass sphere (single raindrop) and a white-light projector (sun) or, as an alternative, cylinders of transparent materials (glass, plexiglas, glycerol) and a collimated white light beam or laser beams at different wavelengths. The quantitative analysis of the experiments is carried on by taking pictures/movies of the setup and processing them with free analysis softwares like Tracker Video (Tracker).

We have tested the didactic path with second-year university students attending a physics laboratory to calibrate each step of the path. Then we proposed the path to a number of High School classes (second-
year students of a scientifically oriented course) by involving the class teachers. Finally we repeated the course as a one-week stage for selected fourth-year students of a scientifically oriented High School course. We will present some comparative analysis of the results obtained by the different activities.

2. Method

In this section we describe the essential of the didactic path we have followed.

2.1 The starting point: observe the phenomenon

First of all, we propose the observation of a number of images of outdoor rainbows in different atmospheric conditions to identify the characteristics common to all of them: a definite order of colors, the presence of water drops suspended in the air, white light (sunlight and moonlight) illumination...

![Figure 1. Example of pictures of natural rainbows shown to students at the beginning of the activity.](image)

2.2 Build up the physical model

Then we run a brainstorming session with students to point out the elements necessary to describe the rainbow: raindrops suspended in the air, white-light illumination, relative position of drops, light source and observer, dependence on the observer’s point of view. We then try to devise a way to reproduce the natural phenomenon indoor in order to answer all the questions that arise from the observation. Where does the light come from and why it comes back? Why does the incoming white light become colorful? Why do the colors remain separate and do not merge into white light? Why does the rainbow appear different when we change observation point?

2.3 Reproduce the phenomenon in the school laboratory

We use a glass sphere (instead of a water drop), a white-light lamp (instead of the sunlight) and a screen to build an indoor setup reproducing the essential of the rainbow. The light source is a simple 50 W halogen lamp slightly collimated by a positive lens (focal length $f = 7$ cm) mounted in front of the lamp holder. The glass spheres (refractive index $n = 1.52$) can have different diameters (we used 10 or 11 cm, but there is no limit) according to the space we have in the laboratory. The sphere is typically located 80-100 cm away from the light source and a screen with a hole is inserted between them. The screen can be either opaque, so that the observer can look at the rainbow from the side of the lamp, or translucent, so that the observer can align the eye on the direction of the rainbow colors (see Fig. 3). Note that when we use the opaque screen we are not in the configuration of the atmospheric rainbow, with the observer in between light source and drops, but we have the advantage to observe on the screen the entire spectrum produced by the glass ball.
Figure 2. Simple equipment to realize the indoor rainbow.

We observe that the indoor model reproduces all the characteristics of the natural phenomenon: correct order of colors, circular symmetry, dark and bright zones.

Figure 3. Setup for the indoor rainbow. The rainbow can be observed by either part of the translucent screen.

Note that the observation must be carried out in the dark even when using very intense lamps.

2.4 Simplify the model

To begin understanding the phenomenon, we need to observe the path of the light inside the “drop”. As this is difficult due to the spherical geometry of the glass ball, we simplify the model by using a cylinder made of a transparent solid material (plexiglas, refractive index $n=1.49$) or a cylindrical pyrex glass container (refractive index $n=1.47$) filled with glycerol, which, having the same refractive index as pyrex glass, minimizes optical effects at the interfaces.

We shine the cylinder with a light (either a collimated white light or laser pointer beams) in the horizontal plane and observe its path from above (see Fig. 4). We can study the light path in the cylinder as a function of the incidence angle by taking pictures of the setup and analyzing them with Tracker video (Tracker).
We can thus observe many optical phenomena that need to be understood: refraction, reflection, dispersion, non trivial dependence of the emergence angle on the incidence one, existence of a maximum emergence angle different for the different colors, existence of a primary and secondary emerging ray.

The simple model of the behavior of the light beam in the rain drop results to be correct if, based on it, we can explain the entire phenomenology of the rainbow.

2.5 Dismantle the rainbow by analyzing any single physical process

2.5.1. Change of direction at the first surface: REFRACTION

We observe the change in the direction of a light beam with respect to the normal to the surface when it crosses the interface between the air and the cylinder of transparent material.

We move the incidence direction parallel to itself to change the incidence angle and observe that the direction inside the cylinder depends on the angle of incidence and that the behavior of angles is reversed at the exit of the cylinder. We guide students to make some systematic observations that will lead to the qualitative formulation of Snell’s law: we find a non-trivial proportionality between incident and emerging angles. The quantitative derivation of Snell’s law can be obtained by further simplifying the model by taking a flat surface instead of a curve one. The observations can thus be carried on by using standard didactic components, such as slabs of transparent materials and ray lamps. By drawing on the table the scheme in Fig. 5, Snell’s law can be recovered even without using trigonometry.

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
\[ \frac{AO}{OD} = \text{costante} = n_2 / n_1 \]

**Figure 4.** Path of monochromatic beam from a laser pointer inside a cylinder of pyrex glass containing glycerol.

**Figure 5.** Simple geometrical construction to verify Snell’s law.
2.5.2 Different refraction angles for different colors: DISPERSION

Observe dispersion for the different materials both at the entrance and at the exit from the cylinder. Systematic observations of the dispersion properties of different materials are then carried on by using prisms and by observing that for prisms also a dependence of the exit angle of each color on the entrance angle does actually exist. Moreover, by rotating the prism with respect to the incident light, the existence of a condition of minimum deviation of the outgoing light can be seen.

2.5.3 Coming back of the light from the back of the ball: REFLECTION

Observe and verify Cartesius law of reflection at the back surface of the cylinder and observe the reflection angle is equal to the incidence angle independent of the color of the light. Once again, systematic observations of Cartesius law can be more easily performed by using flat mirrors or any slab of reflecting material.

2.5.4 Observation of the existence of a maximum exit angle different for different colors

The analytical calculation of the emergence angle as a function of the incidence angle at a single frequency does not require advanced mathematical skills and can be easily performed by high school students. We realized a simple program by using the free software Geogebra (Geogebra) to reproduce the results.

The exit angle of each color has a maximum as a function of the incidence angle: this is the main reason why the colors in the rainbow result clearly distinguishable as “stripes” around a given angle. This is probably an unexpected result even if a similar behavior is displayed by the prism.

The observation is performed by using a beam splitter to superimpose two laser beams at different colors. The beams enter the cylinder along the same direction but exit at two different angles (see Fig. 6).

Figure 6. Setup for the observation of the exit maximum angle with two laser lights at different wavelengths. The laser lights are superimposed at a beam-splitter to enter the sphere along the same directions.

To enforce observations we have performed numerical simulations by starting from some demonstrations made by using Mathematica (Wolfram) to show the dependence of the emergence angle on wavelength and on material refractive index (see Fig. 7).
2.5.5 Observation of the Intensity dependence on the angle

Around the inversion angle each color rays accumulate and light intensity increases making the rainbow stripes very bright. Again the use of Mathematica allows the demonstration of the effect (see Fig. 8).

2.5.6 Dependence of the observed color from the relative positions sun-drop-observer

Figure 7. Simulation of the dispersion of the light diffracted by a sphere of transparent material for different values of the refractive index.

Figure 8. Simulation of the emerging angles as a function of the incidence angles for different light wavelength: the more numerous the rays the more intense the light.

Figure 9. Collection of the rays of different colors that build the rainbow. For, the primary rainbow, the higher the drops, the longer the wavelength of the collected light, for the secondary rainbow the higher the drops, the shorter the wavelength of the collected light. The result is that primary and secondary rainbows have inverted colors.
At large distances any observer catches a single color from each drop that depends on observation position: many drops are needed to build a rainbow and each observer “sees” a different rainbow. For primary rainbows, red light is collected from higher drops and blue light from lower drops. The reverse holds for secondary rainbows (see Fig. 9).

3. Results

We tested the path with three different groups of students having different initial expertise and skills: second-year Physics students at University of Insubria in Como, two entire classes of second year students (15-16 year old) of a scientifically oriented High School (Liceo Scientifico) and a group of volunteer fourth year students of Liceo Scientifico.

The group of second-year University students was used to individuate the steps of the path and to test the procedures and to devise technical solutions, such as the use of a cube beam splitter to superimpose two laser beams of different colors (Fig. 6) or the camera position to take pictures from above without introducing aberrations. The work with this group of students lasted about 10 hours in three different days.

Figure 10. Different phases of the verification of Snell’s law. Panel (a): ray lamp and plastic slab used for the measurements; panel (b): one of the picture of the refracted beam taken with a compact photo-camera and analyzed with Tracker; panel (c): values of the sine of the incidence angle as a function of the sine of the refraction angle and evaluation of the refractive index of the material.

To propose the activity to High School students, we prepared a didactical path together with the teachers of the involved classes. Our work consisted in the training of the teachers who were assisted in the preparation of the didactic plan and in particular of the experimental part of the activity. All the lessons were carried on by the teachers who at the end verified knowledge and skills achieved by students.
concerning geometrical optics and demonstrate that the students reached a level at least equal to that reached in the previous years who had traditional didactics. A better comparison work would have been done by using parallel classes following conventional didactics as a control but it was not possible due to the unavailability of other teachers of the same school.

Finally we proposed the rainbow program as a one-week stage to a group of fourth-year High School students. They followed the path by setting up the experimental apparatus necessary to see all the effects from a qualitative point of view and were also able to make several rather precise quantitative measurements, such as the verification of Snell’s law (see Fig.10) and the evaluation of the dependence of the angle of the beam emerging from the cylinder as a function of the incidence beam (see Fig.11).

![Figure 11](image-url)

**Figure 11.** Different phases of the measurement of the deviation of the exit angle from the incident one. Panels (a) and (b): laser pointer and cylinders (glycerol and plexiglas) used for the measurements; panel (b): ray tracing of the beam path; panel (c): values of the deviation angle as a function of the incident one: experimental data from ray tracing (blue diamonds) and theory (red squares).

The students devised their own method to measure the angles, calculated the analytical relations between the measured quantities and produced theoretical predictions to be compared with experimental data.

4. Discussion and conclusions

The entire didactic path covers all the topics included in a standard optics curriculum for High School students. At the end of the activity, each student will have learned at least the basics of geometrical optics, probably experiencing a higher interest and satisfaction.

One of the strong points of the path is the requirement of following the scientific method step-by-step in order to reach the final correct interpretation of the experimental results. What is interesting is that...
to answer some of the initial questions we need to introduce non trivial hypoteses that must be verified. For instance, to understand why we can distinguish the colors in the rainbow, we first of all observe the path of monochromatic light in the sphere (or cylinder) finding that there exist a maximum angle for the light emerging from the sphere that is different for the different colors and that around the maximum we have an accumulation of light. The existence of a limiting angle is \textit{a-priori} not trivial but it can explain many features of the rainbow simultaneously, such as the order of the colors, the visibility of the colored strips and the dark region outside the colors. The application of rather simple mathematical tools allows the students to develop the model and to make prediction on different systems (different refractive index, different colors). This is a direct experience of the scientific method.

Some critical points emerged from the implementation of the path by direct observation of students’ action and by students’ and teachers’ comments. The first problematic issue is time: more time is needed to lead a group of students through the observation of the phenomenon to the discovery of its explanation than it is needed to simply transfer information in frontal lessons. For this reason traditional didactics is often preferred by teachers as it is less time consuming. Moreover teachers need to spend some time to prepare and practice the experiments. A second issue is connected with teachers’ skills in laboratory didactics: teachers must be able to face unexpected laboratory problems and unexpected observations by students and must be able to use them as a part of the discovery process. This requires a deep understanding of the phenomena, that can only come from a large amount of personal work on the subjects.

Future developments of this work will be devoted to the implementation of the didactic path in some High Schools under the direct responsibility of the teachers that will be supported and trained so as to overcome their difficulties and distrust of new ways of teaching.

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The Teaching of Concepts of Electromagnetism, Optics, Waves, and Modern and Contemporary Physics: Using Situations in Medical Science

Mara Fernanda Parisoto, Federal University of Rio Grande do Sul / Graduate Program in Physics Teaching, marafisica@hotmail.com
Marco Antonio Moreira, Federal University of Rio Grande do Sul / Graduate Program in Physics Teaching, moreira@if.ufrgs.br
José Tullio Moro, University of the Association of Higher Education Institutions of the Sinos River Valley, Novo Hamburgo (FEEVALE), tullio@feevale.br

Abstract

In this paper we emphasize the importance of prior knowledge, which was registered by the fourth application group of a 40h physics course as well as in a questionnaire used with this purpose, taking into account that there are not many articles related to prior knowledge of physics applied to medical science. To attain the objectives proposed in the research methodology, we proceeded by following these steps: 1) a review of the literature in the journals classified by CAPES (a Brazilian agency for graduate courses) as A1, A2 and B1, from 2000 to 2009; 2) development of a questionnaire; 3) validation of the questionnaire; 4) modification of the questionnaire when needed; 5) reliability/validity calculation; 6) application of the instrument to look for evidences of prior knowledge. Based on this research, we have been able to develop pedagogical materials aiming at the teaching of physics applied to medical science. Besides, we carried out a broad scope research project in this area according to the theoretical framework of Ausubel’s (2002) Meaningful Learning Theory, Moreira’s Critical Meaningful Learning Theory (2005), Vergnaud’s (1990) Conceptual Fields Theory, and of Toulmin’s (1977) epistemology. Research findings suggest, among other things, that the teaching of physics applied to medicine seems a scarcely researched area; the use of differentiated methodologies, within the framework of the aforementioned theories, might have helped facilitate the occurrence of meaningful learning evidences; the use of computer simulations together with experimental activities seem to have favored meaningful learning; feedback has been shown to be relevant to the teaching of physics applied to medicine; guiding questions can be rather applicable to the development of computer simulations. This proposal may be applicable to the high school context, to teacher education courses, as well as to the formation of physics undergraduates.

Keywords: physics teaching, physics applied to medicine, meaningful learning.

1. Introduction

Research on medical applications of Electromagnetism, Optics, Modern and Contemporary Physics has allowed for the development of an alternative proposal for the teaching of physical concepts. As a means to do this, it was crucial to know which would be the specific high school contents that could be used in physics applied to medical science and which would be the most potentially favorable pedagogical approach(es) to promote meaningful learning in this area.

The scientific and academic relevance of this paper resides on its potential of offering a discussion about new possibilities for the teaching of physics with the use of materials that can help make classes more meaningful through the implementation of an interactive and creative environment. Such a context would support physics learning, while looking for applications to medical science of Electromagnetism, Optics, Modern and Contemporary Physics could bring improvements to physics teaching.
The 40-hour course was divided into five sections, and each began with the use of an advance organizer, followed by a problem-situation. Afterwards, there was, in each of these sections, a short lecture. These mini-lectures were intercalated with some easy construction and low-cost experimental activities, computational simulations, games, cartoons, exercises, concept maps, diagrams, debates, films and assemblages.

The following applications were used: ultrasonography, natural exposure and nuclear accidents, human eye functioning and some eyesight shortcomings (astigmatism, nearsightedness, hypermetropia), functioning of conventional radiography and mammography, fluoroscopy, digital fluoroscopy, radiographic image, teletherapy, Brach-therapy, Computerized Tomography (CT), Computerized Helicoidal Tomography, Magnetic Resonance (MR), radiation detectors, Nuclear Medicine, Positron Emission Tomography (PET), Single-Photon Emission Tomography (SPECT).

Thus, the focus of this study question zoomed into how to teach physics concepts that were necessary for the understanding these applications in courses for physics teachers and future high school physics teachers as well as for people who use ionizing radiation in their work.

There was, then, the option of organizing and implementing a course that taught physics applied to medical science, within the theoretical framework of Ausubel’s Meaningful Learning Theory (2002), Moreira’s Critical Meaningful Learning Theory (2005), Vergnaud’s Theory of Conceptual Fields (1990), and Toulmin’s Epistemology (1977). Because of the limited allowance of pages for this paper, these theories are just referred to, though they are adequately described in Parisoto (2011).

Therefore, there seems to be a substantial need for the production of instructional materials aiming at helping high school teachers to bring their teaching of physics closer to the students’ reality and, thus, helping to make it more interesting to the students. These materials could eventually become potential facilitators of meaningful learning.

The main objective here was the development of alternative instructional materials that would enable students to learn meaningfully, instead of mechanically. With this in mind, the produced materials were evaluated in order to improve them, and, for this purpose, there were questionnaires and also semi-structured interviews, to which participants responded. Pre-tests and post-tests were applied to participants, so as to verify possible evidences of meaningful learning. This evaluation was both qualitative and quantitative, which means that we used data triangulation to carry out evaluating procedures.

Summarizing, specific objectives of this proposal were:

1. organizing, developing, and implementing a course with the aforementioned theoretical background;
2. looking for contents of Optics, Electromagnetism, Modern and Contemporary Physics that could be used in physics applied to medical science;
3. looking for evidence that such an application can facilitate meaningful learning of physics;
4. identifying the students’ prior knowledge in order to teach them accordingly;
5. helping students to meaningfully understand the production of X-rays (characteristic Bremsstrahlung), the interaction of radiation with matter, radiographic image, image processing, radiographic exposure factors, physical factors in the quality of images, analogical fluoroscopy, digital fluoroscopy, operation of the apparatus of conventional X-rays, mammography, nuclear tomography, computed tomography, digital radiography, Nuclear Magnetic Resonance and Nuclear Medicine;
6. identifying the operational invariants of students in the field of physics applied to medicine;
7. finding alternatives to explicit the identified operational invariants;
8. identifying what could be the best use of concept maps in the teaching and learning of physics applied to medicine;
9. verifying the possibilities of implementation of this proposal at high school level;
10. substantiating whether this implementation facilitates the occurrence of meaningful learning of the content involved in this research.

The proposal was not implemented in regular classes, but as an extension project, in which some groups had a small number of participants because of those who dropped out along the implementation of the course. This might have thwarted the quantitative analysis of collected data. Another limitation was the technological infrastructure of the local implementation of the proposal, which lacked the necessary apparatus to be used in this study. So, it was decided that just two of the four groups had the necessary conditions to be quantitatively compared.

Nonetheless, it is suggested that such proposal can be broadly applied in other countries and also that it is feasible to use the results originated from the application context to establish a comparison between/among them. This practice could come as an antidote to the shortage of global studies on the integration between physics and medical areas. This dearth has been identified in an extensive literature review encompassing 38 journals, from 2000 to 2009, in which there were only 38 articles dealing with Applied Physics in Medicine, out of which not a single one used the same approach described in this study.

The periodicals surveyed here conform to the requisites for top-level journals, according to the parameters of the Brazilian agency that regulates graduate courses (CAPES), both national (11) and international (27), from 2000 to 2009, which are the following: The American Journal of Physics; Caderno Brasileiro de Ensino de Física; Ciência & Educação; Enseñanza de las Ciencias; International Journal of Science Education; Investigaciones em Ensino de Ciências; Journal of Research in Science Teaching; Physics Education; Revista Brasileira de Ensino de Física; Revista Electrónica de Enseñanza de las Ciencias; Revista Enseñanza de la Física; Science Education; The Physics Teacher; Revista Brasileira de Ensino de Ciência e Tecnologia; Revista Electrónica de Investigación en Educación en Ciencias; Revista Eletrônica do Mestrado Profissional em Ensino de Ciências; Experiências em Ensino de Ciências; Revista Brasileira de Pesquisa em Educação em Ciências; Research in Science & Technological Education; Journal of Science Communication; Public Understanding of Science. The complete results of this research are in Parisoto, Moreira, and Moro (2012a).

Some of the studies that deserve attention are briefly described in the next paragraphs.

Aiziczon and Cudmani (2007) used two questionnaires with students of medical science to detect what sort of prior knowledge in the students’ cognitive structure could either hinder learning, or serve as subsumers to the learning of a given topic. These findings may support activities to improve the teaching of physics in the area of health studies. This study provided the following research findings:

- students do not adequately discriminate sound wave and acoustic perception;
- they demonstrate some state of uncertainty to discriminate between wave and vibration and between noise and sound;
- they do not adequately relate intensity and pain, and intensity and frequency in relation to the human ear.

Kortemeyer (2007) suggests tests for pre-med students in order to know how physics has been taught to them and to know whether they believe it to be an important discipline in the curriculum. His main objective has been to develop a curriculum that would link contents of physics to their needed application to medical science. Research findings suggest that many pre-med students express their interest in medical imaging, as in examples of anatomy and blood circulation, and that students do not seem to be aware of the linkages between physics and medical science. Kortemeyer, then, proposes what might be a solution to this situation: 1) handbooks or textbooks that establish a connection between physics and medical science and/or life sciences; 2) the teacher should use examples from the medical field; 3) the use of a more conceptual approach; 4) the use of a problem-solving strategy. In addition, the author proposes an order of contents that should be used in the discipline of physics applied to medical science.
Anderson et al. (2009) carried out an experimental activity to demonstrate the functioning of the human respiratory system. In this experiment, there is a digital blood pressure monitor and a real-time integrated computer to display changes that result from variations of pressure linked to the different stages of respiration. Such experimental model was connected to a virtual data collecting system called Bio Pac. This device was used to teach 427 students taking the discipline Physiology in college. They were randomly divided into two groups (experimental and control). The following methodology was applied: 1) a pre-test; 2) reading about the functioning of the respiratory system; 3) experimental activity; 4) post-test. The experimental activity did not occur in the control group; the questions in the post-tests and pre-tests were identical for both groups and the same teacher applied them. ANOVA statistical test was used to compare pre-tests and post-tests of both groups. Statistical significance indicator was lower than 5%, which is a significant value. The authors concluded that the mechanical respiratory model is a valuable institutional tool in the teaching of the respiratory system.

In the articles specifically related to the applications of physics to medical science, we can refer to those of Machado, Pleitez and Tijero (2006) that present the way antimatter has its applications in Positron Emission Tomography (PET); Carneiro et al. (2000) that describe the development and applications of a new interface between physics and medical science, which is called Biomagnetism. Guimarães (2000) enumerates some of the major characteristics of NMR and its importance to the study of magnetic materials.

In general, it is possible to say that research on students’ prior knowledge, though highly developed in areas such as mechanics, thermodynamics, optics, and/or electromagnetism, is still rather scarce in the area of physics applied to medical science.

Some studies show that students have a hard time to understand knowledge of physics related to medical science, hence, there have been attempts to focus on this issue, some of them involving experimental activities and new technologies, though their findings are still far from being conclusive.

In terms of numbers, interest in the application of physics to medical science seems to be constant, though apparently small along the variable time. Adding up articles in Brazilian and international periodicals in the first five years comprised in this research, there are only 19 articles, and, in the last five years, once more, there have been 19 articles. However, it might be noticed that there seems to have occurred an increase in Brazilian publications, whereas there has been a decrease in international ones.

2. Methodology

We have used a variety of tools, such as a supporting text, experimental activities, new technologies, concept maps (Novak, Gowin, 1984) and problem-situations (Vergnaud, 1990). Such tools were applied along four instances of implementation of a course, which used concepts of physics applied to medicine directed to people that used ionizing radiation in their work, to high school students, and to teachers and future teachers of physics. Through qualitative and quantitative analysis, we investigated whether these tools had favored the students’ meaningful learning.

To achieve the proposed objectives, we followed these steps: 1) a review of the already mentioned literature 2) a study of alternative materials for the development of instructional resources to be used in the course (Parisoto and Moro, 2010a; Parisoto and Moro, 2010b); 3) development of suggestions for educational activities; 4) organization of semi-structured interviews, pre-tests and post-tests; 5) application of the designed course; 6) application of the interviews, pre-tests and post-tests so as to look for evidences of meaningful learning; 7) data analysis; 8) course improvement; 9) re-application of the course; 10) re-application of the interviews, pretests and post-tests; 11) data analysis to verify evidences of meaningful learning instances; 12) comparison between the groups of this study to search for indications of what would be a good way of teaching such a content.

Our attempts here focused on looking for evidences of meaningful learning in this proposal, thus, we compared the pretest and posttest of each group and the obtained results from these groups were also compared using non-parametrical statistical analysis. The results were triangulated with qualitative research instruments (Parisoto, Moreira, & Moro, 2012b), such as concept maps (Novak, & Gowin, 1984),
exercises, recordings of the students’ discussion on situation-problems (Vergnaud, 1990), notes from a logbook, development and presentation of a V diagram (Novak, & Gowin, 1984).

Due to the scope of this research, this article will have an in-depth focus on the questionnaire, which was used in the implementations of this proposal and which aimed at identifying the students’ prior knowledge that is a scarcely researched topic in this field. An early version of this questionnaire in its pilot application has been already published (Parisoto, Moreira, & Moro, 2012c).

The questionnaire initially had 37 questions involving the following applications: ultrasound scanning, functioning of conventional radiography and mammography, fluoroscopy, digital fluoroscopy, radiographic imaging, teletherapy, brachitherapy, Computed Tomography (CT), Helicoidal Computed Tomography (HCT), Nuclear Magnetic Resonance (NMR), radiation detectors, Nuclear Medicine, Positron Emission Tomography (PET), and Single Photon Emission Computed Tomography (SPECT).

It was, then, was handed in to four teachers of the Federal University of Rio Grande do Sul (UFRGS), Brazil, so as to have them validate the selected content. They made some changes and offered suggestions to improve it.

Afterwards, it was sent to some graduate students of physics, teachers and undergraduate students of physics, with a major in Physics Teaching. Sixteen subjects of this group responded to the questionnaire. Cronbach alpha coefficient was then calculated and a value of 0.796 was found for the 37 questions. Seven (7) questions were taken out of it because they presented a low correlation in relation to the other questions, and afterwards we got Cronbach coefficient of 0.865. However, according to Silveira and Moreira (1989), in order to get a Cronbach alpha value that has a low level of statistical fluctuation influence, the number of respondents should be, at least, five times larger than the number of questions. Thus, the questionnaire was re-formulated: 30 questions to be applied to 250 respondents (teachers of the state public system of Santa Catarina, Brazil, and college students enrolled in the discipline of Introductory College Physics at the Federal University of Rio Grande do Sul, Porto Alegre, Brazil), that is, 250 respondents represent more than five times the number of questions. Cronbach coefficient was 0.864 that, according to Vianna (1978), is rather adequate to such an instrument.

As aforementioned, this is a 40 hour-course distributed along four weekly presential meetings of 8 hour each, and eight hours of distance learning. Further information on this course can be found in Parisoto, Moreira and Moro (2012d).

The questionnaire attempts at verifying the students’ prior knowledge, and is the focal point of the present article, so as to share it with the community.

At the opening of the first meeting, students received the questionnaire (Parisoto, 2011) comprising 30 multiple-choice questions. In the last meeting, students responded again to this instrument with the purpose of looking for evidence of which of their inadequate knowledge constructions had eventually become scientific knowledge, as well as which of them had not been modified. These data supplied evidence concerning what should be improved in the proposal and also evidence on the role of the proposal in the occurred changes.

At first, it was applied in two implementations of this proposal, though what we emphasize here are the findings of the last implementation, whose complete description is in Parisoto (2011).

3. Data And Findings

Looking at Table 1, the questions that might have presented a larger number of errors/mistakes were:

- 1, 2 and 30 had each three mistakes;
- 14, 19 and 25 had each four mistakes;
- 9 had five mistakes;
- 3 had 6 mistakes;
Those with a larger number of correct responses were 5 and 8, with 10 correct responses each.

Table 1: Summary of obtained data

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic</th>
<th>Mistakes</th>
<th>Correct answers</th>
<th>Do not know</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ultrasound</td>
<td>3-b</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Ultrasound</td>
<td>1-b 2-d</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Radiation production</td>
<td>6 1</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Radiation production</td>
<td>0 6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Photoelectric effect</td>
<td>0 10</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Compton effect</td>
<td>2 3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Production and annihilation of pairs</td>
<td>0 2</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Magnetic field</td>
<td>0 10</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>X-Rays</td>
<td>2-c 3-d</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>X-Ray Machine and Mammography</td>
<td>2</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Fluoroscopy</td>
<td>1</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>12</td>
<td>Radiographic image formation</td>
<td>0 2</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>13</td>
<td>Radiographic image formation</td>
<td>0 4</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>Radiographic image formation</td>
<td>0 4</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>Radiographic image formation</td>
<td>0 7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>16</td>
<td>Radiotherapy</td>
<td>0 3</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>Radiotherapy</td>
<td>1 7</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>18</td>
<td>Gas Detector</td>
<td>0 6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>19</td>
<td>Scintillation Detector</td>
<td>1 4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>20</td>
<td>Thermoluminescence Detectors</td>
<td>0 4</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>21</td>
<td>Optically stimulated thermoluminescence</td>
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<td>3</td>
<td>10</td>
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<tr>
<td></td>
<td>detector</td>
<td></td>
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</tr>
<tr>
<td>22</td>
<td>Solid State Detectors</td>
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<td>2</td>
<td>10</td>
</tr>
<tr>
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<td>Film Detector</td>
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<td>4</td>
<td>8</td>
</tr>
<tr>
<td>24</td>
<td>Helicoidal Computed Tomography</td>
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<td>2</td>
<td>11</td>
</tr>
<tr>
<td>25</td>
<td>Nuclear Magnetic Resonance</td>
<td>4 1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>26</td>
<td>Nuclear Magnetic Resonance</td>
<td>0 7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>27</td>
<td>Tomography</td>
<td>0 5</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>28</td>
<td>Nuclear Medicine</td>
<td>0 3</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>29</td>
<td>Nuclear Medicine</td>
<td>4 3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>30</td>
<td>Nuclear Medicine</td>
<td>1 1</td>
<td>1</td>
<td>11</td>
</tr>
</tbody>
</table>
4. Discussion and final remarks

As this research area is quite new, there are not many papers on it, and besides they present a variety of differences among themselves, as for instance, a focus on a different subject and diverse methodological choices. Therefore, it is quite impossible to compare their results with the findings of the present research proposal. We might infer here, based on the data listed in the last section, the following students’ misconceptions, or alternative conceptions, when considering them under a scientific point of view:

- ultrasound waves have a lower frequency than those audible by human beings;
- ultrasound devices transform electric current into electric energy;
- sound is used in Ultrasound Exams;
- there is less connecting energy close to the nucleus;
- electrons do no have to have high energy to produce, when braked, X-Rays;
- when there is more intensity in the X-Rays beam, we need the same lead breadth to block it;
- in conventional X-Rays exam, the denser tissue will appear as darker points in the radiographic image;
- the amount of light emitted by scintillation detectors is inversely proportional to the amount of light absorbed by the material;
- Nuclear Magnetic Resonance uses ionizing radiation;
- isotopes have different atomic numbers;
- radioisotopes do not emit radiation;
- radioisotopes, used in Nuclear Medicine nuclear always present higher levels of radiation than X-Rays and tomographies.

The questions about which more than half of the students reported a lack of knowledge of the topic were 4 and 18 with seven questions each; 6, 14, 19, 23, 25, and 27 with 8 questions each; 10, 13, 14, and 20 with 9 questions each; 16, 21, 22, and 28 with 10 questions each; 7, 11, 12, 24, and 30 with 11 questions each. Therefore, along the course, the following actions were emphasized to curb such needs:

- to explain how the production of radiation by braking occurs;
- to stress differences and similarities between Compton effect and photoelectric effect;
- to explain what the Compton effect is; parameters that have to be followed for its occurrence; the consequences of X-Ray imaging; and the harmful side effects of radiation to the human body;
- to explain what the photoelectric effect is; parameters to be followed for its occurrence; the consequences of radiographic imaging; and its harmful side-effects to the human body;
- to explain production and annihilation of pairs;
- to explain the functioning of the image intensifier;
- to differentiate fluoroscopy from conventional radiography;
- to relate voltage difference in the X-Ray equipment with the energy of X-Rays;
- to relate X-Ray energy with the imaging characteristics produced in the film;
- to relate electric current to the imaging features produced in film;
- to explain the functioning of all necessary elements to produce a radiographic image;
- to relate density of organic tissue with the features of the imaging produced in the film;

1 The complete version of the analysis can be found in Parisoto (2011).
• to explain what radiography is, and how it is divided;
• to explain differences and similarities between teletherapy and brachitherapy;
• to explain what the radiations used in radiotherapy are, and how they kill cancer cells;
• to explain the functioning of a gas detector and relate it to the photoelectric effect;
• to explain the functioning of scintillation detectors;
• to explain the functioning of thermo-luminescent dosimeter;
• to relate the radiation to which the thermo luminescent dosimeter is exposed with the radiation it emits, when the temperature of the material is increased;
• to explain the optically stimulated luminescence process;
• to explain the functioning of solid state detectors and relate it to the photoelectric effect;
• to relate intensity of radiation to the darkening of the image;
• to explain the functioning of Helicoidal Computed Tomography;
• to differentiate Computed Tomography from Helicoidal Computed Tomography;
• to differentiate Nuclear Magnetic Resonance from Tomographies and from conventional X-Ray exams;
• to explain the functioning of sliding rings;
• to explain why in a Helicoidal Computed Tomography detectors and emitters move around the patient in a 360° degree, while in other tomographies they move around in a 180° degree;
• to explain the functioning of Nuclear Magnetic Resonance;
• to explain how a radiopharmac is produced;
• to explain what a radioisotope and an organic molecule are, and the function of each of them in PET and SPECT;
• to explain the functioning of PET and SPECT;
• to differentiate the radiation used in Nuclear Medicine from the other exams that use ionizing radiation.

Therefore, with the use of these prior knowledge evidences and theoretical references as a basis, we were able to develop support materials, described in Parisoto and Moro (2010b). The use of such material seems to have favored evidences of the occurrence of meaningful learning (Parisoto, 2011).

As final remarks, we can say that we have presented basic notions for the organization of a physics curriculum that used medical science as its context. We have started with a sequence of topics, for which we might find evidence of facilitating the occurrence of meaningful learning (Parisoto, 2011).

Findings of the application of the proposal (op.cit., 2011) suggest that it has brought encouraging results related to meaningful learning, that is, we can find evidences of meaningful learning in students that have learned according to the sequence of topics we suggest here. Therefore, this proposal seems to be a viable alternative for the teaching of concepts of Physics in context and in a meaningful way.

This proposal has also shown that it can be used in different levels of schooling, such as with future physics teachers, in continuing education programs of teachers’ education, and with high school students as an alternative mode for teaching and learning in the area of the application of physics to medical science, a field of study that has not yet motivated many research projects nor the writing of papers in periodicals.

It seems important to emphasize the relevance of using the theoretical framework we have proposed here to motivate students to get engaged in their own learning, that is, in meaningful learning (Ausubel, 2002); the role of relating concepts and contextualizing them (Vergnaud, 1990) and the development of critical thinking in students (Moreira, 2005). In our view, it might have been important to show
those students the evolution of science, especially in the process of change from Classical Physics to Modern and Contemporary Physics. We have emphasized that concepts can be better organized, so as to favor the solution of new problems. Thus, this can encourage students not to drop out, but to go on in a study program, even though, in some instances, they do seem able to solve novel problems and, consequently, might get unwilling to continue taking a study program (Toulmin, 1977). It was helpful to use a methodological framework, both qualitatively (André, 1998) and quantitatively (Campbell, 1979).

This is an ongoing research, and nowadays we are trying to integrate Project Method (Rogers, 1977) to the Potentially Meaningful Teaching Units (Moreira, 2011) so as to attain a potentially meaningful teaching of physics based on medical science situations and events using data triangulation.

### 5. Acknowledgement

We thank the contributions of Alex Sandre Killian, Glaucio Pantoja and Nathan Pinheiro.

### References


6. Appendix- Questionnaire applied to the course to verify students’ prior knowledge.¹

**QUESTIONNAIRE ABOUT SOME CONCEPTS OF PHYSICS**

This questionnaire aims at getting information on what the students already know (prior knowledge) about some concepts of Electromagnetism, Optics, Modern and Contemporary Physics.

*Instructions*: each question presents different alternative propositions. Select just the one you feel is the most adequate. The answers are not of the “right” or “wrong” type. The questionnaire intends to measure how close your prior knowledge is in relation to scientific knowledge. It is not the purpose here to verify whether “you know and/or do not know” something. Please, avoid wild guessing. However, if you do not know the answer, please, mark the option “I don’t know”.

1. **In your understanding, ultrasound:**
   a. Is an ionizing radiation.
   b. Is a sound wave with a non-audible frequency by human beings.
   c. Is harmful to health.
   d. Is manifested by the modifications it yields in its propagating means. X
   e. I do not know.

2. **The ultrasound equipment:**
   a. Has a sound probe of crystals that present only a piezoelectric effect.
   b. Transforms electric current into electric energy.
   c. Transforms mechanical energy (ultrasound waves) into electric current. X
   d. Uses gel to increase intensity of ultrasound.
   e. I don’t know.

3. **When electrons are taken from the atom electrosphere** (e.g. by an electronic capture), the vacancy it originates is filled right away with an electron of lesser orbitals. When this electron passes from a more linked state to a lesser linked state (more removed from the nucleus), it liberates its excess energy by emitting electromagnetic radiation, whose energy is equal to the difference between the energy of the initial state and of the final one. This process is called characteristic radiation production.
   a. I agree.
   b. I disagree. X
   c. I don’t know.

4. **When an electron (negative) passes very close to a nucleus (positive)**, it experiences an electric attraction force and it is deviated from its original direction. While it changes direction, it loses kinetic energy. This lost kinetic energy by the atom is emitted in the form of a photon. This process is described as radiation emission by braking.
   a. I agree.
   b. I disagree. X
   c. I don’t know.

¹ The “X” indicates the right answers.
5. **Photoelectric effect** has various applications, such as, taking the information captured by the eyes to the brain, more specifically, to the cerebral cortex. Photoelectric effect is the capacity light has, when knocking off a metal target, to eject electrons. Electromagnetic waves comprise photons (energy bundles) that, when knocking off on an electron, can supply it with enough energy to let it loose from the atom (photoelectric effect). a) I agree.

   b. I disagree. X
   c. I don’t know.

6. **In the Compton effect**, quite different from the photoelectric effect, the electron does not have enough energy to get unloose from the atom, it just absorbs totally or partially the photon energy. When the electron absorbs the energy totally, it moves to a more external layer. When it returns, the electron emits the absorbed radiation. In case it absorbs only part of the energy, there are two waves: one that results from the layer change and the other results from the deviation of the photon incidental radiation in the electron, as expected according to the angular moment conservation.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

7. **Annihilation processes and pairs production** came from the need of explaining the results of the Dirac equation, which has as solutions a negative and a positive energy. Dirac took for granted that all levels of energy had already been taken, so that energy electrons could not fall into a negative energy “hole”. This “hole” of negative energy is interpreted as an antiparticle (antimatter), for instance, a positron. The inverse process can occur, when a positive energy electron fall into a “hole”. In this case, a photon would be emitted, whereas the electron would be annihilated by the “hole”.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

8. If we have two reels, they can function based on the following process: **alternate electric current** in the first reel generates a variated magnetic field in the second reel, which, in turn, produces in it an alternate electric current.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

9. Concerning **X-Rays**, it is correct to state that

   a. It is a type of ionizing electromagnetic radiation. X
   b. They need a material medium in order to radiate since they do not propagate in the vacuum.
   c. They are produced when low-energy electrons are suddenly decelerated.
   d. They can be blocked by lead, which girth does not depend on the X-Rays energy.
   e. I don’t know.

10. In the intensifier, **image** is produced according to the following sequence: light photons are transformed into an X-Ray photon that generates the electric current, which, in turn, generates the image.

    a. I agree.
    b. I disagree. X
    c. I don’t know.
11. Fluoroscopy functions with higher doses of radiation than the other X-Rays equipment, so that, even when the time of exposure is the same, radiation doses that get to the patient are higher in fluoroscopy.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

12. When the value kVp is increased (voltage difference between the cathode and the anode in the X-Ray equipment), we also increase the X-Ray energy and, consequently, the radiation capacity of penetrating the patient, thus affecting the imaging contrast. As to lower values of kVp, photons do not have enough energy to traverse the patient, as they are absorbed, consequently, this requires a higher radiation dose. Thus, as the same value for the electric current (measured in milliamperes) is maintained, the lower the value of kVp, the clearer the image in conventional X-Rays exams.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

13. X-Rays get initially to the screen, a film that in contact with the X-Rays produces that presses the film in which the image is produced. The film is shielded by the radiographic chassis, which does not allow for the film to be sensitized by other radiations.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

14. When an organic tissue has low-density, the image will be darker in conventional X-Ray exams; thus, it will have high radiographic density. Photons that are attenuated or spread will reach the screen with high-density because of the girth of the patient and the tissue density, and will produce an image in different hues of grey.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

15. In a radiographic image, contrast is defined by the difference between the optical densities of the objects. Components that can be radiographed are muscles, fluid, adipose tissue, gases, and bones, and the first three mentioned have similar densities and, thus, they do not have much contrast in the radiographic image.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

16. Radiotherapy is a treatment method that consists of the destruction of the cancer cells, especially in the cellular multiplication stage, using electromagnetic ionizing radiations (X-Rays and Gamma-Rays), as well as corpuscular radiations (beta and alpha particles), which have high frequency and are more energizing. Radiotherapy can be of two types: teletherapy (external) and brachitherapy (internal).

   a. I agree.
   b. I disagree. X
   c. I don’t know.
17. **Accelerators** are circular tunnels that are used to accelerate particles until they reach very high-level energy, so as to emit, besides X-Rays, bundles of electrons and neutrons of varied energy. The cyclotron is an example of accelerator, of which one of the best known today is the LHC (Large Hadron Collider). They do not have any radioactive material inside them.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

18. A **gas detector** comprises a gas-filled tube in which there is an electrode along its central axis. If a potential difference between the central electrode and the wall is created, so that the electrode is positive and the wall is negative, the electrode will attract electrons yielded by ionization inside the tube. Electrons will form an electric signal, like an electric pulse or a continuous current. The electric signal is amplified and measured. Its intensity is proportional to the intensity caused by radiation that caused it.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

19. **Scintillation detectors** are formed by light emitting materials that do so after having absorbed an X-Ray photon. The amount of light it emits is inversely proportional to the amount of energy absorbed by the material.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

20. **Thermo luminescent dosimeters** are made of a material that, when submitted to heat, liberates its exceeding energy (such as, for example, generated by radiation contact) this emitted energy is measured and its value indicates the amount of radiation to which the dosimeter was exposed.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

21. In the **optically stimulated luminescence**, irradiation of aluminum oxide stimulates some electrons to an excited state. During this process, a laser light stimulates these electrons so that they go back to their original state with the resulting emission of light. Light intensity is proportional to the radiation dose received.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

22. **Solid-state detectors** are made of a phosphoric-based material that scintillates (emits light) with the radiation passage. Light incises on the detector nucleus and emits electrons (photoelectric effect), originating an electric current that is inversely proportional to the incidence of the photon (radiation).

   a. I agree.
   b. I disagree. X
   c. I don’t know.

23. In the **film dosimeter**, radiation alters the density of the processed film. So, we can quantify radiation exposition since the lower the radiation intensity the higher the darkening of the image.

   a. I agree.
   b. I disagree. X
   c. I don’t know.
24. In **Helicoidal Computed Tomography**, unlike in Computed Tomography, the radiation agent and the detectors perform a 360° turn around the patient. For this purpose, optical fiber cables were replaced with sliding rings. In one of the equipment surface this ring is smooth while in the other it has electronic contacts that get information from the smooth one. Such information is usually emitted by radiofrequency.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

25. **Magnetic Resonance** is also called Nuclear Magnetic Resonance. It is a very modern exam that uses ionizing radiation, gamma rays, which are produced in the nucleus, thus, nuclear.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

26. **Nuclear Magnetic Resonance** uses magnetic fields and radiofrequency. In the absence of an external magnetic field, spin orientation is random. When the main magnet is applied on a magnetic field, the magnetic momentum vector aligns itself with the field (equilibrium state) When the stimulus ends, spins go back to their original alignment, liberating energy as radiofrequency waves, which are caught by reception antennae.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

27. Two elements are called **isotopes** if they have an equal number of electrons and diverse numbers for mass, that is, if they present a different number of neutrons.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

28. **Nuclear Medicine** consists of administering a radiopharmac, which incorporates two components: a radioisotope (emitting particle of beta, alpha, gamma radiation) and an organic molecule with preferential attachment to a given tissue or organ.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

29. **Radioisotopes** used in Nuclear Medicine decrease in a matter of days, hours, or even minutes. They have a higher level of radiation than X-Rays and computed tomography. Urine and/or feces eliminate their radiation.

   a. I agree.
   b. I disagree. X
   c. I don’t know.

30. In **Positron Emission Tomography** (PET), a positron-emitting radioisotope is used. When they shock, the positron and the electron annihilate themselves and the emit gamma rays.

   a. I agree.
   b. I disagree. X
   c. I don’t know.
If you want to justify any of your answers, please, use the space below:

_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

We thank you for the attention and availability to respond to this questionnaire. This information is fundamental for the development of classes on physics applied to medical science.
Coherent Structure of Classroom Discourse in Teaching Physics Concepts

Eizo Ohno, Faculty of Education, Hokkaido University, Japan

Abstract

This study proposes the analytic methodology using dynamic semantic theory and applies the rhetorical relations of SDRT to interpret science classroom discourse in teaching physics concepts. In the first stage of interpretation, the rhetorical relations of SDRT are used to connect each utterance to other parts of the discourse. The resulting intermediate interpretation can be represented as diagrams that clearly identify the coherent structures of the discourse. In the second stage of interpretation, the intermediate interpretation is further analyzed using Toulmin’s Argument Pattern and Walton’s Argumentation Schemes. The survey of teachers’ perceptions of argumentation is also used in the second stage of interpretation. As an example, we analyze classroom discourse teaching dynamics in a lower secondary school. We discuss how this study’s result offers a new perspective on interpreting science classroom discourse.

1. Introduction

Science teachers have to focus on interactive activities in their classrooms because the discourse of science classrooms gives us rich educational information (Ogborn, Kress, Martins and McGillicuddy, 1996; Mortimer and Scott, 2003; Erduran and Jiménez-Aleixandre, 2008). In this study, we propose a framework and methodology for analyzing science classroom discourse. The objectives of this research are as follows.

We use the two-stage process of interpretation (Ohno, 2012). In the first stage of interpretation, a physics classroom discourse is interpreted using the rhetorical relations of Segmented Discourse Representation Theory (SDRT) (Asher and Lascarides, 2003), yielding an intermediate interpretation represented as a diagram of the rhetorical relations.

Using Toulmin’s Argument Pattern (TAP) (Toulmin, 1958/2003) and Walton’s Argumentation Schemes (Walton et al., 2008) in the second stage, we investigate the diagrams obtained in the first stage. The intermediate interpretation is also compared with the teachers’ perceptions of argumentation in science classrooms. In response to a survey (Yoo et al., 2012), the physics teachers drew their perceptions of argumentation and these drawings were used to analyze the intermediate interpretation.

2. Method

Figure 1 illustrates the study’s two-stage process of interpretation. In the first stage, reliance on linguistic information is maximized and reliance on non-linguistic information, such as beliefs and intentions, is minimized. An intermediate interpretation of classroom discourse is constructed by inferring rhetorical relations of SDRT. Specific rhetorical relations are inferred using non-monotonic logic, that is, common sense. A discourse has a coherent structure when all utterances of the discourse are connected to those of others and all anaphoric expressions have been solved. For example, consider the following conversation:

Teacher: (T1) This is a cable. (T2) This is hot.
Student: An electric current is running.
Interpretation of classroom discourse

2nd Stage
e.g. TAP, Argumentation Schemes
using rich non-linguistic information

Intermediate interpretation
diagrammatic representation

1st Stage
Inferring rhetorical relations of SDRT
To maximize reliance on linguistic information
To minimize reliance on non-linguistic information

Data of classroom discourse

Figure 1. Two-stage process of interpretation

The teacher’s utterances (T1 and T2) are connected with CONTINUATION. If you connect the utterances of the teacher and student with the rhetorical relation of EXPLANATION, the phrase “an electric current” by the student is considered to mean that “an electric current” is running through the cable, which the teacher mentioned in utterance T1. This discourse is considered coherent.

The intermediate interpretation is represented as a diagram. There are two types of rhetorical relations in SDRT, “coordinating relations” and “subordinating relations.” Every coordinating relation is represented by a horizontal arrow. Every subordinating relation is represented by a vertical arrow. CONTINUATION and EXPLANATION are a coordinating and subordinating relation, respectively. Figure 2 illustrates the intermediate interpretation of the foregoing discourse.

In the second stage, the interpretation is completed using non-linguistic information, teacher’s intention, students’ beliefs, among other, using TAP and Walton’s Argumentation Schemes.

The survey investigation was obtained and analyzed teachers’ perceptions of interactive activities in classrooms. Fifteen Japanese teachers reviewed their past teaching activities in response to the survey. Three teachers drew their perceptions of argumentation using the elements of TAP. In the second stage, we explain how the teachers’ drawings correspond to the elements of the diagram.

This is an electric cable.
Continuation
This is hot.
Explanation
An electric current is running.

Figure 2. Diagrammatic representation
**Problem 7**
The cart with mass 1 kg is pulled with a 100 g brick. Investigate the motion of this cart and sketch a v-t graph.

**Problem 8**
Change the mass of the brick to 200 g. What happens to the acceleration?

**Problem 8**
Fig. A shows that a cart with mass 1 kg is pulled with a 100 g brick. Fig. B shows that a cart with mass 2 kg is pulled with a 200 g brick. Compare the accelerations of the both carts.

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**Dynamics: Problem 10**
(in a lower secondary school)

There are two balls. One is 100 g and the other is 200 g.

What is the magnitude of the gravitational force on the balls?

- **a. A ball of mass 100 g.**
- **b. A ball of mass 200 g.**
- **c. Almost same.**

**H**: (H1) The carts each were pulled by the 100 g brick and 200 g brick in Problem 7. (H2) The acceleration of the cart pulled by the 200 g brick was double.

**M**: (M1) The 1 kg cart in Problem 8 corresponds to the 100 g ball in this problem, and the 100 g brick corresponds to 100 gw force. Similarly, the 2 kg cart corresponds to a 200 g ball in this problem, and the 200 g brick does to 200 gw force. (M2) The experiment of Problem 8 showed the same acceleration. (M3) This problem will show the same result.

**A**: (A1) I change my choice from c to b. (A2) In Problem 8, both the carts had the same acceleration. (A3) The cart in Figure A was 1 kg. If you change the cart in Figure B for a 1 kg one, ... (A4) in this case, the acceleration must be twice as much as that in Figure A. (A5) Therefore I select b. (A6) M should think under the condition of using the same carts. (A7) In Problem 7, the cart was 1 kg. First, the cart was pulled with a 100 g brick. Next, it was pulled with a 200 g brick. (A8) The acceleration of the cart pulled with a 200 g brick was twice as much. (A9) Therefore, in this case, the acceleration of a 200 g ball will be larger.

**M**: (M4) A spoke about the case in which the carts have the same mass. (M5) In this case, the mass of each ball is 200 g and 100 g. (M6) Therefore, A should considered different weight carts.

**G**: (G1) I agree with A. (G2) The gravitational pull of the earth is related to mass. (G3) Um, the larger the mass is, the larger the pulling force is. I think so. (G4) So the larger force for a 200 g ..., (G5) therefore, the gravitational pull is larger for a 200 g ball. (G6) Therefore, a 200 g ball reaches the ground first.

**S**: (S1) The mass is in inverse proportion to the acceleration, though. (S2) According to what G said, only the mass becomes zero.

**R**: (R1) I think, the mass is in proportion to the weight, and, ... (R2) the acceleration is in inverse proportion to the mass. (R3) Both balls reach the ground at the same time.

**Y**: (Y1) By choosing b you pay your attention to only the force. (Y2) You do not consider the mass.

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**Figure 3.** Science classroom discourse at a lower secondary school

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3. Data and Findings

This section reports the analysis results for a science classroom discourse. Figure 3 illustrates the record of classroom discourse in a lower secondary school (Takamura, 1987). This discourse described students’ efforts to understand the dynamics of a free fall. In this lesson, they considered Problem 10 shown in Figure

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3. Every student selected one of the three options (a, b, c) and discussed their choices with each other. Figure 4 illustrates the intermediate interpretation of this discourse, demonstrating that this discourse is coherent.

The students had already learned the results of Problems 7 and 8 (Figure 3). Student H who selected option b, talked about Problem 7. Student M who selected option c, attempted to consider Problem 10 as compared to Problem 8. Student A had selected option b and explained his reasoning using the result of Problem 7. They considered Problem 10 by applying, in their own way, their previous experiences. When exploring the advanced topic of the Seebeck effect at an upper secondary science class, not mentioned in this paper, students lacked sufficient previous experiences, thus, the discourse was not coherent.

We can identify several segments in the diagram in Figure 4. Segments SEG2, SEG3, and SEG4, each consist of reasoning from presumption to conclusion; potentially the reasoning is defeasible. In SEG2 and SEG3, the students compared Problem 10 and the previous problems, and based their inferences upon the result of the previous experiments. Using Walton’s Argumentation Schemes, these segments can be interpreted as an argument from example and that from analogy.

If we consider the reasoning in SEG2 and SEG3 as defeasible reasoning from Data to Claim, we create two TAP-like structures from these segments. One of the TAP-like structures consists of SEG2 and SEG3, which are connected with the rhetorical relation, CORRECTION. SEG3 can be regarded as something like Rebuttal to the inference in SEG2. Segments SEG3, SEG4 and SEG5 consist of another TAP-like structure illustrated in Figure 4.

In the survey investigation, a physics teacher had produced Figure 4’s drawing (a), which can be applied to interpret the intermediate diagram. The two TAP-like structures consisting of SEG2 through SEG5 are considered a chain of arguments. The teacher who drew this picture explained in the interview that the Rebuttal of a TAP became the Data of the next TAP. These TAP-like structures seem to relate to the teacher’s drawing (a). Another physics teacher explained the drawing shown in Figure 4 (b) as Backing, representing a type of natural laws that students learned in previous lessons. He explained that a Claim appeared from the Backing during a classroom discussion. If we think of student utterances G2 and G3 as Backing, utterance S2 as Rebuttal, and utterance G6 as Claim, this part of the diagram relates to the teacher’s drawing (b).

4. Discussion and Conclusions

In this study, we used the two-stage process of interpretation to analyze classroom discourse in teaching physics concepts to lower secondary students. An intermediate interpretation was represented as a diagram using the rhetorical relations of SDRT. We applied TAP and Walton’s Argumentation Schemes to the intermediate interpretation in the second stage.

The segments of discourse can be easily understood from the diagrammatic representation of the intermediate interpretation. TAP-like structures were constructed from a chain of discourse segments. Each segment was considered as Walton’s Argumentation Schemes of argument from analogy or that from example. Thus, the diagrammatic representation of intermediate interpretation appears to be helpful in conducting further analysis using various coding systems as well as TAP and Walton’s Argumentation Schemes.

We have explored the relationship between the diagram and teachers’ drawings of argumentation obtained in the survey investigation. We related two teachers’ drawings with elements of the diagrammatic representation of intermediate interpretation. Therefore, we suggest that teachers can apply the relationship between their own drawings and the diagrams to reflect upon how argumentation among students is embedded in classroom interactive activities. Although the example diagrams represent other teachers’ lessons, the same principles apply.

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References


A Comprehensive Assessment Strategy for Physics Laboratory Courses

Rajesh B. Khaparde, Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, V. N. Purav Marg, Mankhurd, Mumbai 400088, INDIA

Email: rajeshkhparde@gmail.com

Abstract

The objective of physics laboratory training is to develop, in students, a variety of important cognitive and psycho-motor abilities related to experimental physics. These include conceptual understanding, procedural understanding, experimental skills and the experimental problem solving ability. It has been noted that strategies adopted for the assessment of what students learn and develop through a laboratory course are often inconsistent with the objectives of the laboratory courses. The author has developed a comprehensive assessment strategy which can be used at the school, college and university level. The strategy is based on four tools of assessment, namely, test on conceptual understanding, test on procedural understanding, an experimental test, and the continuous assessment. The relative weightage for each of the four tools depends on the level and emphasis of the laboratory course. The four tools of assessment, with respect to the type of questions, design, grading schemes, administration of each tool have been described with a few sample questions for each tool of assessment. This assessment strategy is being practiced and its effectiveness studied during a series of special courses in experimental physics in India. Furthermore, a survey was carried out with university teachers from across India to check the acceptability and feasibility of using this strategy for larger number of students in universities and most of the participating teachers supported the use of this strategy.

Keywords: Physics laboratory course, assessment strategy, tools of assessment, conceptual understanding, procedural understanding, experimental skills, continuous assessment

A Comprehensive Assessment Strategy for Physics Laboratory Courses

1. Introduction

Assessment of laboratory performance has always been a matter of concern and discussions during faculty meetings in colleges and universities. However, it has not been given its due importance by the Physics Education Researchers and university administrators as far as developing and implementing novel strategies of assessment are concerned. A few researchers have reported noteworthy developmental work on laboratory performance test and strategies for physics laboratory courses (Wall, (1951); Kruglak, (1954); Kruglak, (1958); Moreira, (1980); Theysohn, (1983). In this paper, a comprehensive assessment strategy for physics laboratory courses is described, which the author had developed as part of a major project on development of ‘contents’ and ‘strategies’ for training in experimental physics (Khaparde, 2009).

It is well accepted that physics laboratory courses are supposed to develop in students important cognitive, psycho-motor, attitudinal and affective abilities related to experimental physics, which essentially include, conceptual understanding, procedural understanding, experimental skills and experimental problem solving ability. In accordance with these major objectives, the assessment strategy should have suitable assessment of all four aspects with appropriate weightage for each and the final grading should be only on the basis of the convergence of the results obtained through such multiple tools of assessment.

The assessment strategy presented below is based on four tools of assessment namely i) a test on conceptual understanding, ii) a test on procedural understanding, iii) an experimental test and iv) continuous assessment which is based on students regular laboratory work throughout the course. The first two are paper and pencil type tests, which correspond to a single variable each, namely, the...
level (or score) of a student’s conceptual understanding and the procedural understanding, respectively. The third focuses around the variable ‘experimental skill’, but is not a single variable measure; rather it is a composite measure of the experimental skills, problem solving ability, conceptual understanding, and procedural understanding. It is difficult to isolate the contributions of each of the four variables to this composite measure. In the following subsections various tools of assessment referred to above are described in detail.

2. Test on Conceptual Understanding

Conceptual understanding is the understanding of concepts, their interdependence and ideas in science, which are based on facts, laws, and principles. According to this strategy, the first tool of assessment is a ‘common for all’ pen and paper type written test to quantitatively measure the students’ conceptual understanding developed in students through a laboratory course. This test is essentially ‘context linked’, i.e., the questions have a direct link to or an application of the conceptual understanding involved in the experiments and demonstrations. The context or the situations around which the questions are framed are new and novel. This is essential to evaluate the extent to which the students have developed conceptual understanding through the given laboratory course.

The majority of questions in this test consisted of ‘multiple choice’ questions. It also had ‘match the pairs’ and ‘fill in the blank’ type of questions. Some questions involved drawing or completing a figure or a schematic/ray diagram. The text in the questions was supported by schematics or figures to clearly explain the ‘question’ to the students. This test was validated and thoroughly discussed with the teaching faculty members. Each student was given a question paper. Students were asked to mark their answers on the question paper itself, which were collected after the test and hence no separate answer paper was necessary. Blank papers were provided to the students for carrying out rough work. Students were given ample time to answer the given set of questions. In the grading scheme, marks were assigned for the correct answer as per the difficulty level of the question. The marks allotted to each question and to the whole test itself were decided by the number of questions and the level of difficulty. The students were informed about the grading scheme during the tests. To illustrate the ‘contents’ of a test on conceptual understanding, a few sample questions on conceptual understanding are given below.

1) Water drops are freely falling vertically down from the nozzle of a tap at regular intervals. Which of the following picture is most appropriate to describe the line of falling drops?

![Image of water drops](image)

a)  

b)  

c)  

d)  

e)  

2) A student is given three laser sources which emit light of wavelengths $\lambda_1$, $\lambda_2$ and $\lambda_3$. When he illuminates a diffraction grating by these laser sources keeping the distance between the grating and the screen the same, he observes the given pattern of bright spots on the screen. What can you infer about the wavelengths $\lambda_1$, $\lambda_2$ and $\lambda_3$?
3) Which of the following statement(s) you think is/are not correct?

a. An equi-potential surface is a surface composed of all those points having the same value of the potential.

b. No work is involved in moving a unit charge around on an equi-potential surface.

c. There is no potential difference between any two points on this surface.

d. The electric field is normal to equi-potential surfaces.

e. The electric field at any point on the equi-potential surface is the same in magnitude.

4) A transformer is designed with two coils primary and secondary, each of 500 turns of copper wire of the same cross section, wound on the central leg of an ordinary laminated iron core. The resistance of the wire used for primary coil is 2.9 Ω and the resistance of the wire used for secondary coil is 3.8 Ω. (The secondary coil is wound over the primary coil).

The secondary coil is left open and the primary coil is connected to a 230 V, 50 Hz power supply. The peak current passing through the primary coil is found out to be 200 mA. If the secondary coil is shorted, the current in the primary coil will

a. increase
b. decrease
c. remain the same
d. will be near to zero

5) The emf induced in a wire by its motion across a magnetic field does not depend upon.

a. The length of the wire
b. The diameter of the wire
c. The material of the wire
d. The orientation of the wire
e. The magnetic field strength

3. Test on Procedural Understanding

According to Gott and Duggan (Gott, 1995) procedural understanding is the ‘thinking behind the doing’ or the decision-making in designing and performing experimental activities. It is the understanding of a set of ideas or concepts of evidence related to the ‘knowing how’ of science and related to designing experiments, planning measurements, observations, analyzing, and interpretation of data. It was felt that the significance of procedural understanding is subsumed and therefore lost under the rubric of ‘experimental skills’ (Khaparde, 2002). Thus according to the strategy, the level of procedural understanding, which is a cognitive understanding in its own right, should be measured quantitatively by the students’ performance in
a separately designed ‘common for all’ test on procedural understanding. This being ‘conceptual in nature’, it was felt that a written test with appropriately framed questions based on experimental situations should be designed. It was noted that this type of test is not a replacement of an experimental test in which procedural understanding and various other abilities are synthesized to solve the given experimental problem.

In this test, there were ‘descriptive’, ‘essay’ type, ‘multiple choice’, ‘fill in the blank’ and ‘match the pairs’ type of questions. The questions were ‘context free’, i.e., these questions had no direct bearing on a set of experiments and demonstrations included in the laboratory course. This test was very carefully designed and validated. The test had questions on various aspects related to the how, why and what of the design, measurement and data handling, e.g., devising a procedure for measuring a particular parameter, choosing an appropriate instrument, understanding relationships in instruments, determining the range and accuracy required, exercising warnings, controlling parameters, changing parameters, measures to reduce errors, variable structure, choosing values, sampling the data, the intervals between the readings, reliability, and validity of data, data representation, etc.

Each student was given a question paper along with an answer paper. Students were provided blank papers for necessary rough work. The question paper, the answer paper, and the blank papers were collected at the end of the allotted time for the test. Students were given ample time to answer the given set of questions and were informed about the grading scheme during the test. On account of variation of content, length of expected answers and difficulty levels, it was necessary to give different weightage to different questions in the grading scheme. To work out the grading scheme, a detailed model answer for each question was prepared, analyzed, and accordingly the marks were allotted to each question.

To illustrate the ‘contents’ of a test on procedural understanding, a few sample questions on procedural understanding are given below.

1) A rectangular body of material with known density has a cubic cavity inside it. Design and explain an experimental method to determine the size of this cavity and locate its position.

2) You are given a spring, known masses and a meter scale. Suggest an experimental method to determine the mass of the spring.

3) In an experiment, you are supposed to study the variation of resistance of a thermistor with temperature. In this experiment, which instruments will you need? Which parameters will you keep the same? Which parameters will you change and the change in which parameters will you record?

4) In an experiment to determine the coefficient of viscosity of a liquid, the liquid is transferred through a siphon made of a plastic tube of uniform cross section from one cylindrical container to the other of identical cross section and height. The expression, which is to be used for the determination of viscosity is,

\[ \eta = \frac{a^4 \rho g t}{(4R^2 L) h (H_0/H)} \]

where, \( \eta \) is the coefficient of viscosity of the liquid, \( a \) is the radius of the inner cross section of the tube, \( \rho \) is the density of the liquid, \( g \) is the acceleration due to gravity, \( t \) is the time, the liquid takes to flow through the siphon, corresponding to the difference of levels of the liquid \( H \) in the cylinders, \( L \) is the length of the tube (\( ?2m \)), \( H \) is the difference in the liquid levels in the two containers, initial value of which is \( H_0 \) and \( R \) is the inner radius of the cylindrical container.

In this experiment which quantities will you measure? Explain your choice of instrument for the measurements involved in the above experiment. Which quantities will you measure more accurately and why?
4. Experimental Test

According to the strategy, experimental skills and problem solving ability should be quantitatively measured through a separate experimental test. Hence, the third tool of assessment was an experimental test. It is noted that the experimental test gives a composite measure of students’ conceptual and procedural understanding, experimental skills and problem solving abilities required to effectively solve the given experimental problem. However since all these components of the composite measure are integrated with each other, separating their individual effect is hardly possible in such a test.

An identical experimental test was given to all the students. This ensured that all the students were tested on the ‘same ground’. The experimental test was carefully designed to involve experimental skills and experimental problem solving abilities. Every student was individually given the set of necessary apparatus, the question paper, the answer paper, blank papers, and graph papers. The question paper had the necessary details of the experimental test such as the objectives, apparatus, description of the apparatus, useful data, and the statement of the experimental problem. The students were asked to report, all the steps they have devised and followed, measurements, data, data analysis, and interpretation in a systematic manner. They were asked to report each and every observation taken and the procedural step followed. This comprehensive reporting allowed the graders to grade the students’ performance after they complete the test based on only the report in their answer papers.

In accordance with the strategy, the students’ performance was graded entirely through their comprehensive reports, totally avoiding subjective judgments based on the ‘observations’ and ‘interrogations’ by the grader/examiner. This was an important aspect of the strategy of assessment of students’ performance in an experimental test (this strategy is regularly being used in the International Physics Olympiads). This considerably reduces the subjectivity of assessment present in the traditional strategy. Thus, teachers or examiners present in the laboratory during the test are not supposed to interact with the students, unless a student needed to consult them for technical reasons.

The grading scheme was carefully designed to evaluate the students’ performance with respect to various aspects and abilities, which the experimental test is supposed to evaluate. First the required data was collected, a model answer was prepared, and various stages of the solution of the experimental test were identified. Only then the relative weightage for different stages was decided. It was felt that students’ reporting is also an important aspect and hence some marks were reserved for reporting and presentation of the laboratory work. Marks were allotted to the experimental skills (reflected from the discrepancies between the expected and the reported data), understanding and application of the necessary theory and concepts, collection, organization and analysis of data, and overall approach towards handling the given experimental problem. For example, the statement of the problem for the experimental test on ‘efficiency of a light emitting diode’ was “Design and perform the necessary experiment to a) show that the current generated in the photodiode is linearly proportional to the intensity of the light falling on its sensitive area, b) study the variation of the efficiency of an LED with the current passing through it, and c) determine the total radiant power emitted by the LED and calculate its maximum efficiency.”

5. Continuous Assessment

It was felt that it is important to monitor and evaluate students work during the regular laboratory course. Student’s report of each experiment should form an important component of the assessment. Thus the fourth tool of assessment was continuous assessment based on students work in the laboratory and their reports. Students were asked to record every procedural step they adopted during the experimental work, observations, method, detailed data, data analysis, final results, and inferences in their reports. It was necessary that students complete the report of a given experiment before proceeding to the next one. The teachers were asked to observe the students during the laboratory course. The teacher were expected to continuously grade and correct the report of each experiment and give detailed comments, feedback, and the marks. The final marks had a combination of all the individual scores. A substantial portion of the total marks were reserved for this ‘continuous’ assessment.
6. Evaluation of the effectiveness of the strategy

This assessment strategy is being practiced during training of students and teachers and its effectiveness was studied at HBCSE-TIFR Mumbai, India (http://www.hbcse.tifr.res.in) through a series of special courses in experimental physics. From the students grades and feedback, it was noted that this assessment strategy is comprehensive, objective, valid, and reliable as an achievement test, as compared to the traditional assessment strategy being used for laboratory courses in India. This strategy is being employed as a regular assessment strategy at University of Mumbai-Department of Atomic Energy-Centre for Excellence in Basic Sciences, Mumbai, India (http://www.cbs.ac.in) and a few other undergraduate institutions in India.

Furthermore, a survey was carried out with 45 university faculty members, to study the acceptability and feasibility of using this strategy for a larger number of students in universities. Detailed opinions and suggestions were collected through a “Questionnaire on Assessment Strategy”. Majority of the participating teachers reported that this was a much better strategy compared to the strategy being used in Indian universities. The teachers supported the use of all the four tools of assessment presented in this strategy, except on the use of identical experimental test for all the students, as this would require a large number of identical experimental setups.

7. Conclusions

This comprehensive assessment strategy involving all the four tools of assessment with an appropriate weightage for each can be used in physics laboratory courses. The first two tools could be administered and evaluated centrally for all the students enrolled for the laboratory course. The relative weightage should depend on the level and objectives of the laboratory course. As an example, for an introductory laboratory course, one may have a) 25% of the total marks for test on conceptual understanding b) 20% of the total marks for test on procedural understanding c) 25% of the total marks for the experimental test, and d) 30% of the total marks on the continuous assessment.

It is essential to realize and appreciate the fact that the assessment strategy, based on which each student is assessed and given grades that appear in the final score, is a factor which directly or indirectly affects the importance and the effectiveness of the laboratory course.

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An Inquiry-Based Approach to the Distribution Concept in Statistical Mechanics

Onofrio Rosario Battaglia, Claudio Fazio and Rosa Maria Sperandeo Mineo

UOP_PERG (University of Palermo, Physics Education Research Group), Dipartimento di Fisica, Università di Palermo, Italia.

Correspondence concerning this article should be addressed to Onofrio Rosario Battaglia, Dipartimento di Fisica, Università di Palermo, Viale delle Scienze, Edificio 18, 90128 Palermo, Italia. E-mail: onofriorosario.battaglia@unipa.it

Abstract

The distribution concept is a fundamental component of statistical thinking. This paper describes a teaching method aimed at analysing the concept of distribution in its characteristic aspects, like average value, more frequent value, variance, variability etc. A very specific activity related to the field of statistical mechanics, is proposed, in which the concept of the distribution of velocity or the energy of a gas is dealt with using an Inquiry Based experimental examination of Maxwell’s Law. Some outcomes of teaching experiment conducted in a workshop held at the Faculty of Engineering at the University of Palermo, Italy are described.

Keywords: statistical distribution, Inquiry Based Science Education

Introduction

Mathematical representations are relevant to describe and to explain scientific phenomenon, but very often students have difficulty in getting their uses and limits. Many research results have highlighted how much the understanding of the distribution concept in physics can be influenced by the conceptual difficulties connected with its mathematical representation (Leinhardt, Zaslavsky, Stein, 1990; diSessa, Hammer, Sherin & Kolpakowski, 1991). In his classical work “Language of art”, Goodman (Goodman, 1976) outlines that the mathematical representations concerning drawing and interpreting graphs involve the using/understanding of a “symbol scheme correlated with a field of reference”. A semantic analysis of this symbol scheme can highlight some of the central difficulties experienced by students. In fact, it has been emphasized that usually students seem to manipulate symbols without understanding what they mean (Sharma, 2006). Students work with symbols, performing syntactic elaborations, but they do not read information out of this scheme to the reference field, or perform the corresponding semantic elaborations.

The distribution concept is a fundamental component of statistical thinking. It can be seen as a lens through which the variability that exists in various phenomena in the real world can be looked at with greater clarity (Wild, 2006). Examples in Physics are the distribution of values in the analysis of experimental data and their related uncertainties, and the dynamics of the many particle systems. In this last case, the distribution is concerned with the variation of a physical variable (energy, velocity) among the individual particles constituting the system.

Here, we propose an approach to the concept of distribution in its characteristic aspects, like average value, more frequent value, variance, variability etc..., based on laboratory and modelling activities aimed at overcoming the difficulties previously mentioned. For this purpose, a specific activity, related to the field of statistical mechanics, is proposed, in which the concept of the distribution of velocity/energy of a particle system is dealt with by using an Inquiry Based (Linn, Davis, & Bell, 2004) experimental examination of Maxwell’s distribution. In particular, we discuss the experiment and the data processing that allows the determination of the velocity distribution of the electron gas emitted by a metal as a result of thermionic effect (Battaglia et al., 2010).

The described approach has been tried in a workshop for Engineering students and here preliminary results of such teaching experiment will be described. In the following section we describe the theoretical framework on which our approach is based. Then we report the main steps of our approach and some preliminary results of our teaching experiment. In the last section findings and limits of our research are outlined and suggestions are proposed for the improvement of the workshop methodology.
Methodology

Inquiry Approach to Science Education has been variously defined and several specific examples of scientific inquiry have been supplied. Usually organizations into “stages” of scientific inquiry or patterns of inquiry processes (Wenning, 2007, Banchi & Bell, 2008) are illustrated. These involve a continuous spectrum of inquiry levels that accounts for the gradual shift of the focus of research control from the teacher to the student. A didactic approach based on Guided Inquiry (Wenning, 2007) is intended as an approach where the teacher provides students with research questions and guides students in designing the procedures to test their questions and the resulting explanations. According to this theoretical framework the students are encouraged to plan and carry out their laboratory activities by collecting, formulating and analysing data, for the purpose of gaining a more meaningful understanding of the concepts of physics.

“Inquiry is the scientific process of active exploration by which we use critical, logical and creative thinking skills to raise and engage in question of personal interests. Inquiry helps us to connect our prior understanding to new experiences, modify and accommodate our previously held beliefs and conceptual models, and construct new knowledge” (Liewellyn, 2002). Students are therefore inspired by a scientific investigation procedure, very similar to the one followed by a researcher, a very important aspect of which is the modelling of physical phenomena.

In this case the students work in small teams. They are expected to design and conduct the experiment themselves with little or no guidance by the teacher and only partial pre-lab orientation. The students can use some scientific papers on the subject or on similar problems. They can also use a traditional and microcomputer based laboratory for their measurements and data analysis.

This activity should make able students to trace a path similar to the one some physicists have identified to solve the proposed problem in the past. They are requested to formulate hypotheses, conjectures, explanations and to identify the most appropriate methodology for their research. Students can, then, confirm their assumptions and explicative models on the basis of experimental results. In particular, the idea of an “electron velocity filter” by means of electric fields can be very useful because it naturally introduces students to the concept of a distribution of frequencies.

The different stages of the inquiry procedure are summarized in the diagram reported in Figure 1 (Windschitl, Thompson, Braaten, 2008).

Figure 1. The logic diagram of our teaching sequence.
The didactical experimentation

The teaching experiment was carried out during a 20-hour workshop entitled “An experiment on thermo-ionic emissions: the speed distribution of electrons emitted in a vacuum tube”, carried out at the Faculty of Engineering of the University of Palermo from March to May 2012. The workshop involved 43 students that already completed the curricular mathematical and numerical calculation courses, as well as the general physics courses. In such courses they already faced the problem of statistical distributions, although only in terms of continuous functions and only from a theoretical point of view.

The workshop planning took into account the average level of knowledge of a second/third year university student concerning standard physics (mechanics and electromagnetism), mathematical and numerical analysis, as well as the ability to use software like calculation sheets.

Evaluation of the workshop approach as well as assessment of student learning has been performed through the administration of a questionnaire and a qualitative analysis of videos registered while the experiment was underway.

In this paper, the teaching experiment effectiveness is evaluated by comparing the answers to pre-instruction/post-instruction questionnaires and by taking into account some preliminary results of video-analysis. The administered questionnaire was aimed at investigating the previous student knowledge with respect to the distribution concept, and to obtain information for the gauging of the interventions.

A classification of student answers to the questionnaire items, based on a careful reading of students’ answers within a framework provided by domain-specific expertise, has been performed. In particular, our analysis is focused on the cognitive variables and evaluation criteria that refer to the ability to read and construct a distribution, and the ability to compare different distributions.

A phenomenographic analysis (Marton, 1988, Marton and Pang, 2008) of answers to the pre-instruction questionnaire allowed us to identify clusters of reasoning procedures and classify students in groups.

The workshop was structured into five phases (see Figure 1):

1. Presentation of the inquiry context to the students and definition of the main problem by setting the broad parameter to be investigated.
2. Discussion of the different approaches proposed by students by organising what was known and what was to be known.
3. Generation hypotheses
4. Laboratory activity.
5. Data analysis and pointing out of arguments for appropriate explicative model building (Gilbert, 2002, Greca, 2002).

At the end of the workshop the same questionnaire was administered in order to verify the instruction effectiveness.

The Workshop

At the beginning of the first phase, the problem of identifying methods that can emphasize the distribution of some variables (energy, velocity,...) among particles of a system (atom, molecules, electron) was discussed. Student ideas and proposals have been discussed by the whole class and difficulties in performing experiments making evident the various characteristics have been pointed out. The teacher illustrated several scientific publications in which the problem of experimental determination of the velocity distribution of a system of atoms/molecules has been faced. These systems can be divided into two large categories: a first one, that makes use of mechanical apparatuses; another, including electromagnetic type apparatuses. The first type of apparatuses is usually much more complex and requires complicated and expensive equipment. In fact, Maxwell derived this distribution law in 1860, but Miller and Kusch (Miller and Kush, 1955) performed the first rigorous experimental demonstration almost 100 years later by using a mechanical apparatus
For these reasons, the proposed experimental activity is directed towards the second type of apparatuses and the student interest is focused on ways to obtain a system of electrons. Some historical papers were described (Richardson, 1921, Germer, 1925) and the research was oriented toward the following problem:

“To establish the characteristics of the electrons gas emitted by thermionic effect through the typical variables of statistical mechanics”.

The objective of the second phase was to point out what students knew and what they should know by identifying and making explicit their representations about the problem and defining experimental situations that can represent the problem. The awareness of the necessary additional information allow students to make explicit the research question:

“How it is possible to realise an electron velocity analyzer able to show how many electrons have velocities in given intervals?”

During the third phase the design problems connected with the design of such electron velocity analyzer have been discussed. Students have been guided in recalling the characteristics of vacuum tubes, like diodes and in analyzing how an electron velocity analyzer can be easily built by using vacuum a appropriately polarized diode. The emitted electrons can be selected within a given velocity range through retarding potentials, and variations in the electron current can be measured.

In the fourth phase students were divided into groups of up to 4. The groups worked independently by designing the measuring apparatus and using the tools provided by the teacher at their request. Each group was responsible of the experimental setting as well as of the choice of the different kinds of measurements.

All the students understood the need to perform a set of measurement maintaining constant the temperature of emitted electrons (an consequently the filament temperature), although many students were not able to explicitly and formally see the relationship between the values of current end the ranges of electron velocities.

Each group performed two sets of experiments by fixing, for each set, the filament temperature and varying the retarding anode potential from zero to values that allow a current in the range of sensitivity of our micro-ammeter. Figure 2 shows the ratio between the anode current $I$ at a given anode potential $V_a$ and the value $I^*$ ($V_a = 0$) plotted against the anode retarding voltage, $V_{ar}$, for different filament temperatures.

**Figure 2.** Ratio $I/I^*$ plotted against the anode retarding potential $V_a$ for different filament temperatures. Values of $I^*$ are in the range 20-500 $\mu$A
The fifth stage, devoted to data analysis, was preceded by a discussion directed to the formalization of a possible model that would put in relation the current with the electron velocity distribution.

In order to build a model of the electron dynamics, we consider a diode with a regular geometry and a cathode-anode spacing small enough to minimize effects of the space charge. Under this condition, plane parallel geometry may be assumed as a good approximation. In our approximation, a certain retarding potential \( V_r = V \) will influence only one component of the electron velocity (say the \( z \)-component, \( v_z \)) and an electron will reach the anode surface if

\[
\frac{V_r^2 - 2eV}{m} \geq 0
\]  

where \( e \) and \( m \) are the electron charge and mass, respectively.

It follows that the electron current, \( I \), in the \( z \) direction perpendicular to the vacuum tube surfaces \( S \) is

\[
I = eS \int_{v_z}^{\infty} n(v_z) v_z \, dv_z
\]  

where \( n(v_z) \) indicates the number of electrons having a velocity in the interval \( v_z \) and \( v_z + dv_z \), and \( V_{z,\text{min}} = \sqrt{\frac{2eV}{m}} \).

If we indicate

\[
\varepsilon = \varepsilon(V_z) = \frac{mv_z^2}{2}
\]  

we have \( d\varepsilon = \frac{mv_z^2}{\varepsilon} \, dv_z \), and by means of a change of variable we express \( n(v_z) \) as \( n(\varepsilon) \) by obtaining

\[
I = \frac{e}{m} S \int_{\varepsilon_0}^{\infty} n(\varepsilon) \, d\varepsilon
\]  

where \( n(\varepsilon) \) is normalized so that

\[
I = \int_{\varepsilon_0}^{\infty} n(\varepsilon) \, d\varepsilon = n_0 = I_0 \frac{m}{5e}
\]  

and \( n_0 \) is the number of thermionic electrons reaching the anode per unit time and unit surface when \( V = 0 \) and the electron current is \( I_0 \).

If the retarding potential \( V \) is further increased to \( (V + \Delta V) \), a further drop in the anode current will take place

\[
\Delta I = \frac{e}{m} S \left( \int_{\varepsilon_0}^{\infty} n(\varepsilon) \, d\varepsilon - \int_{\varepsilon(V + \Delta V)}^{\infty} n(\varepsilon) \, d\varepsilon \right)
\]  

The second integral on the right-hand side of Equation 6 can be Taylor expanded around the point \( \varepsilon V = \varepsilon_0 \), and, by taking into consideration only the first two terms of such expansion, in the limit of \( \Delta V \to 0 \) we obtain

\[
n(\varepsilon) \propto \frac{dl}{d\varepsilon}
\]  

According to Equation 7, the velocity distribution can be obtained by differentiating the anode current with respect to the anode retarding voltage at each anode voltage (energy) value. Thus, measurement of the anode current as a function of the retarding voltage, coupled with a suitable method of numerical derivation, can lead to the evaluation of the electron velocity distribution.

In order to investigate the shape of the \( n(v_z) \) distribution function it is need to perform a numerical differentiation of data reported in Figure 2, by applying Equation 7, and to fit the derivative points with a half Maxwellian.
Some students were familiar with the methods of numerical differentiation of experimental data by using the simple method of centred finite difference. By applying such methods to data reported in Figure 2 they obtained data reported in Figure 3.

Figure 3. Calculated derivative points of data reported in Fig. 2 for two different values of filament temperatures. Points are fitted by equation $y = A \exp\left(-\frac{mv^2}{2kT_e}\right)$, where $A$ and $T_e$ are the fitting parameters. The distribution functions are normalized such that the area under each curve is equal to 1.

By comparing the results of the different groups the limits of the model became explicit, showing that at high temperatures the model and then the Maxwell distribution is no longer in accord with the experimental data. An example is shown in Figure 4.

Figure 4. An example of bad fit. The experimental data don’t agree with the model

Data and findings

The pre/post-instruction questionnaire is structured with 4 items that are closely linked to the main problem. Below, we report the questions with the relevant results obtained from the pre/post-instruction comparison.

1. A typical apparatus for the study of properties of a gas is the following:
Figure 5. Experimental apparatus: a Miller and Kush mechanical selector of the silver atoms velocity.

In this apparatus an oven emits atoms of silver, which are collimated on a drum (as a screen) that can rotate at a constant velocity. The surface of the drum is covered with a material that emits light when struck by an atom of silver. In this way the atoms leave a persistent trace on the drum and can therefore be detected.

Explain why the drum is maintained rotating.

The answers are categorised in the following levels:

Level 0: Not answer or only partial answers;
Level 1: Student describes the apparatus but does not give any information about the method of selection;
Level 2: Correctly identifies the method of selection;

Item n. 1 specifically describes the type of particle gas and shows a historic experimental apparatus (the Miller and Kush apparatus), with which it is possible to determine the speed distribution of ion gas emitted by an oven with a vacuum inside it, heated to a high temperature. These ions, which are emitted at different speeds, can leave a mark on a drum rotating at a constant velocity, on which the shape of the distribution is thus determined.

Figure 6. Comparison output-input for the item n. 1, $\chi^2 = 30.19; p = 2.8 \times 10^{-7}$. 
We can confidently say that (See Figure 6) there has been a considerable improvement in the post-instruction answers compared with the pre-instruction ones. Although the proposed apparatus was never described during the activity, after instruction all the students were able to at least describe it correctly. Furthermore, 40% of them managed to identify the selection method, clearly explaining it in their answers. The post-instruction answers made it clear that the identification of the selection method in the description of the apparatus had attained a considerable improvement, compared with the pre-instruction.

2. With respect to item 1, graphically represent the shape that you think will form on the screen.

The answers were categorised in the following levels:
Level 0: Not answer or only partial answers;
Level 1: Student identifies something uniform or a point;
Level 2: Student identifies a distribution;
Item n. 2 is closely related to the previous one.

![Figure 7](image)

**Figure 7.** Comparison output-input for the item n. 2, $\chi^2 = 25.42; p = 1.3 \times 10^{-5}$.  

Figure 7 demonstrates the results of this comparison. In this case the students’ post-instruction answers once again showed a considerable improvement with respect to the pre-instruction one. No students managed to identify the correct distribution in the entry test, but after instruction 9% represent the graph of the Maxwell-Boltzman distribution. Furthermore a large percentage (49%) is able to identify some kind of distribution, partially overcoming the obstacles related to the type of selection method. It should be pointed out that a difference exists between this result and the previous one (aimed at identifying the selection method). In fact, the percentage of students who identify some kind of distribution (49%) is higher than the percentage of students who identify a selection method (40%). This inconsistency of our results may be explained by the fact that some of our students were influenced by their knowledge about the Maxwell-Boltzmann distribution without really understand how the apparatus can make evident such a distribution.

3. Observe the following curves representing three Maxwell-Boltzmann velocity distributions at three different temperatures:
Figure 8. Three normalized Maxwell Distribution for three different temperatures.
State the relation between the temperatures, giving reasons for your answer.
The answers were categorised in the following levels:
Level 0: Student does not identify any information about the distribution.
Level 1: Student identifies some information but not the variance or the connection with temperature.
Level 2: Student identifies the variance as a relevant characteristic of distributions and compares them correctly but does not know the connection with temperature;
Level 3: Student identifies the variances, compares correctly them and knows the connection with temperature;

Figure 9. Comparison output-input for the item n. 3, $\chi^2 = 9.16; p = 0.03$. 
As Figure 9 demonstrates, the improvement in post-instruction answers with respect to the pre-instruction ones is considerable, both because the percentage of those who did not manage to identify an answer has decreased, and because 60% managed to correctly identify the variance as a relevant quantity and were able to relate it to temperature. The correct answers were also well explained and complete.

4. If the electrons emitted by the cathode and collected by the anode were all emitted at the same speed, what would be the analytical expression or the graph of the anodic current vs. the tension?

The answers were categorised in the following levels:

Level 0: Not answer;

Level 1: The current does not depend on the velocity of the electrons;

Level 2: The current depends on the velocity but the relation is not known;

Level 3: The shape of the current is constant up to a particular tension value when it becomes zero.

This item partly sets out the same experimental situation in which the students had been operating, but it reverses the logic of the problem. In this case it is assumed that the distribution is known and the question is what the resulting shape of the current vs. tension might be.

In the initial test this question was certainly the most difficult; in fact a very high percentage of the students were unable to answer, as it is shown in Figure 10.

![Figure 10. Comparison output-input for the item n. 4, $\chi^2 = 56.95; p = 2.6 \times 10^{-12}$.](image)

In the post-instruction test questionnaire answers the situation is reversed with respect to the pre-instruction ones. In fact, as Figure 10 shows, more than 60% of students correctly identified the shape of the current, demonstrating that they have understood the close link between current and velocity distribution and therefore also the experimental evidence that the distribution suggests.

**Conclusions**

In this paper we describe a 20-hour workshop laboratory, for undergraduate engineering students of University of Palermo, performed by using an Inquiry Approach aimed at understanding the statistical distribution concept in the field of statistical mechanics.

Students used commercial vacuum tubes and easily available measurement devices in order to see that a Maxwellian distribution can be inferred for thermally emitted electrons in a range of temperatures of about 100 K. The students designed the appropriate experimental set up and analysed experimental data by building graphics and using fitting and numerical derivate methods.

*WCPE 2012, Istanbul, Turkey*
Here, we report some partial results of a teaching experiment mainly devoted at the comparison of pre and post instruction questionnaire analysis. These show that students easily understood the use of the method of retarding potential to build distributions and became able to transfer these methods to other contexts. All students showed the awareness of the need for an accurate experimental design and models able to describe the experimental data. Moreover, although a high percentage of students initially showed difficulties especially in the construction of distributions and in identifying the quantity characterizing the distributions, their active construction of distributions aimed at explaining their experimental data stimulated their understanding of general concepts.

References


Mass is a fundamental multifaceted physical quantity, involved in courses from primary to secondary school. Its equivalence to rest energy is very important as well. Educational literature indicates remarkable problems in high school textbooks, misconceptions concerning $E_0=mc^2$, and a qualitative view of mass, with a teleological connotation. We therefore carried out a research into the learning paths of 42 skilled students attending a modern physics summer school, by means of an interactive tutorial. “Relativistic mass” conception was investigated too, as an important spin-off. Our main findings concerning the classical part of our working sheets were that 76% of students associated mass with mechanical phenomena and that the pre-theoretical conception *quantitas materiae* was rooted in some minds (between 12% and 15% of the sample); only 26% recognized mass explicitly as important in gravitational interaction between bodies, even if gravitational mass was considered by 50% as a parameter describing a generic interaction between bodies. Inertial mass was instead understood as given by Newton’s second law by most students. As for relativistic part, mental representations of mass seemed to be related to students’ learning environment. The young talents were very good at formalizing, mass-rest energy relationship being a striking exception: The “relational level of physical representation” prevails over other “levels”. Eventually, no statistical significant correlation was found between the presence of the concept of mass as rest energy and the understanding level of “relativistic mass” (even if a sort of negative correlation between the former and the latter can be seen in their plot).

**Keywords:** mass-energy, rest energy, *quantitas materiae*, inertial and gravitational mass, “relativistic mass”, skilled students, interactive tutorial, statistical correlation

**Mass from Classical Physics to Special Relativity: Learning Results**

Mass is a fundamental physical quantity, which is necessarily present in every physics course, in schools of all types and levels. According to the prominent historian and philosopher of physics Jammer (2000) «Next to space and time, mass is the most fundamental notion in physics, especially once its so-called equivalence with energy had been established by Albert Einstein. Moreover, it has even been argued repeatedly that “space-time does not exist without mass-energy”». Strictly speaking, equivalence between rest energy and mass was stated in Special Relativity. Burniston Brown (1959) defined mass as «the key term in dynamics». In 2005, Okun wrote: «There is no doubt that the problem of mass is one of the key problems of modern physics. Though there is no common opinion even among the experts what is the essence of this problem ».

This quantity shows a manifold character: Newton introduced the nonphysical *quantitas materiae* – measurable through the product $\rho \times V$ – together with inertial mass (in $F=ma$) and gravitational mass (in universal gravitation law).

In 1905 Einstein showed a new relationship between Newtonian inertial mass and internal energy of a body (in the thermodynamic sense) – that will be called ‘rest energy’ later on – in the particular case of electromagnetic energy emission. Till 1907 he worked out mass-energy equivalence for a wider and wider range of phenomena. During a conference in Salzburg (Einstein, 1909) he decided to mention only the latter among consequences of the theory of relativity, « [...] because it brings about a certain modification of the basic ideas of physics ». In general relativity momentum-energy density is the source of space-time geometry warping, where (rest) energy is equivalent to mass.
Eventually, “relativistic mass”, a construct dependent on speed of a body in a reference frame, is sometimes used as a proper physical quantity, even if nowadays most of the scientific community considers it useless and misleading in terms of teaching (e.g. Fabri, 2007; Okun, 2001).

Educational researches (Lehrman, 1982) pointed out relevant problems in high school textbooks: Confusion between weight and gravitational mass, belief that equal arm scales measure weight instead of gravitational mass, operational definition of inertial mass as \( F/a \) without a non dynamic definition of force (so we are left with a circularity problem). Additional literature (Burniston Brown, 1959) indicates an increase of confusion about the concept of mass when a distinction between «inertial» and «gravitational» mass is made. This implies confusion about their proportionality in turn. Moreover, *quantitas materiae* has generated misconceptions concerning mass-energy equivalence: Mass is ‘converted’ into a generic ‘energy’ (the most frequent one); \( E=mc^2 \) represents ‘conversion’ of mass into energy; energy conservation and mass conservation laws are mixed up. Finally, an important research by Doménech, Casasús and Doménech (1993) showed the presence of a qualitative view of mass in a group of 16- to 18-years old pupils, with a teleological connotation – encouraged by social view of science (Duschl, 1988) – instead of a scientific quantitative conception, where mass is an operative quantity (at least for educational purposes). This is due both to the belief that scientists describe objective reality and to «student bewilderment with the formal [...] numerical reasoning used by scientists». Doménech et al. (1993) classified students’ ways of looking at mass in five categories, being inspired by the solution models worked out by Gorodetsky, Hoz and Vinner (1986). The categories were called *levels of ‘physical representation’*:

1. **Ontological**: Mass as a general property of matter or even identified with matter/bodies/particles; it’s considered a pre-theoretical definition (a theoretical framework is not developed). A typical example is *quantitas materiae*.
2. **Functional**: Mass identified with properties, tendencies or behaviours of the physical system. Ex. inertia on one hand, heaviness on the other hand.
3. **Translational**: Mass identified with another related quantity, such as density/volume or weight (pre-theoretical level)
4. **Relational**: Mass clearly related with other concepts in a theoretical framework (also when not mathematically formalized).
5. **Operational**: Mass as numerical result to be obtained experimentally through «conceivable» and « explicit » operations. Ex. inertial mass as the measure of inertial scales.

In order to perform an inquiry about both the previous problems and, more generically, high-school pupils’ learning of the fundamental but complex concept of mass, we decided to investigate lines of reasoning in 17 to 19 years-old students attending a modern physics summer school. Our research was essentially lead by two questions:

a. How and in which contexts do our students relate themselves to the word “mass” and make use of it? What (mis)-conceptions can be found?

b. How do skilled students interpret the extension from the concept “mass” to “mass as rest energy” in the relativistic context (under the influence of our path)?

**Method**

**Participants**

Students taking part in the school\(^1\) were 23 boys and 18 girls (\( M_{\text{age}} = 18 \) years, age range: 17-19 years). They came from each Italian region, after a severe selection based on the arithmetic mean of their final marks in scientific subjects in the last two school years. Only one student was attending Liceo specializing in classical studies, the others in scientific studies, four of whom in scientific-technological studies.

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1. IDIF O3 modern physics summer school was held at the University of Udine in July 2011.

*WCPE 2012, Istanbul, Turkey*
There were five additional participants: University skilled students, one of whom took part in our activity freely.

**Materials and Procedures**

42 participants, namely 41 high-school students + 1 university student, attended our 90-minute interactive tutorial, including proposals for both individual reflections and group discussions. Each student read and filled in some worksheets (a little booklet) outlining our whole path. The sheets included inner (individual and “group”) questions and a final questionnaire; the “group questions” were to be answered after a brief discussion in small groups.

Since we assert the importance of building a unitary theoretical framework which should account for all mass facets, we worked out a conceptual path on historical basis, starting from mass in some excerpts from Newton’s *Principia*, going through Mach’s (1883) considerations and criticism, in order to arrive to Einstein’s revolutionary conception of mass: The module of momentum-energy four-vector.

The answers to internal questions that might be relevant, the group answers – recorded by a digital video camera – and the answers to the final test were analyzed, both in ‘vertical’ and ‘horizontal’ mode. The former type consists in examination of every answer for all students, first aiming at categorizing the replies on the basis of our research questions, then for finding their distribution in the students’ sample. The latter type is instead a search for correlations among each student’s answers: We wanted to find out their individual ways of ‘looking at’ mass, in order to recognize the profiles pointed out by Doménech et al. (1993).

**Rationale.** More precisely, our path began with Newton’s operational definition Quantity of matter (see Burniston Brown, 1959). An analysis of inertial and gravitational mass concepts in Newtonian physics as well as a glance at the empirical and ‘relational’ Mach’s definition of the former followed. An applet with a vertical light clock was useful to introduce proper time and relativistic time dilation quantitatively, having postulated the invariance of the speed of light in vacuum. Student visualized a particle world-line, as well as a photon world-line, (shown in Figure 1) on a screen. They solved a couple of problems on intervals in Minkowski space-time then, in order to familiarize with the latter, to understand four-vectors and to deduce quadrivectorial momentum in analogy with its classic equivalent: $m$ (Newtonian mass) times displacement four-vector, divided by proper time (a relativistic invariant), taking the limit $\tau \Delta \to 0$. So we obtain.

$$\mathbf{T} = \left( \frac{\Delta t}{\Delta T}, \frac{\Delta x}{\Delta T}, \frac{\Delta y}{\Delta T}, \frac{\Delta z}{\Delta T} \right)$$

We calculated a series expansion of the temporal component of quadrivectorial momentum in the Newtonian limit afterwards, defining this new quantity the relativistic kinetic energy, apart from an additive constant. Finally, we were able to infer and interpret the equation $E_0 = mc^2$, expressing mass-rest energy equivalence, where $E_0$ is the additive constant.

**Classical inner questions.** «Until the XVIII century mass was essentially considered as “quantity of matter”, also by Isaac Newton who in his *Principia Mathematica* (1687) wrote [first quotation]. In the text below, which of the following concepts is prevalent in Newton? Mass, Body, Density or Volume? Why? ». After that we reconstructed the genesis of the famous formula $\frac{F}{\gamma} = G \frac{m_1 m_2}{r^2}$ briefly, through further indirect and direct quotations, compared it with Coulomb’s formula, and asked: « Observe that masses $m_1, m_2$ in the Universal Gravitation Law play the same role than electrical charges. On the basis of this analogy, can you tell what the meaning of the word “gravitational mass” is? ». The last Newton’s quotation was about inertia, as well as the subsequent quotation by Mach (1883), who considered the former formulation as a vicious circle; we asked finally: « Here [quotation] the focus is that mass is no more the simple “quantity of matter” in Newton […]: It’s a concept in evolution in his mind. Is there a difference between the mass in gravitation and this one? Explain». Group question: «What are the conceptual differences ultimately among the notions of mass examined so far? »

**Relativistic inner problems.** Students analyzed a nuclear fission process – of which we provided two examples – and tried to understand where the huge quantity of energy released comes from, if total energy has to be conserved. An analysis of a collision between two identical particles, creating a new rest particle, followed: We asked which forms of energy were changing.
Data and Findings

Classical part

Answers to the inner questions. The first answers show that students acknowledge the contents proposed through the reading, even if with some variations. Density is considered related to mass by 43% of students, and to “quantity of matter” or “substance” – in their words – by 33%. For instance, Luca replies: «Because Newton uses it as reference point (valid for all bodies) to obtain the mass of every body»; Carmelo replies instead: «Because he speaks of quantity of matter in a volume, that is density or what he calls norma of every body». From the second answers we found out that gravitational mass is considered as a parameter describing an attractive interaction between bodies; the emphasis is on the body in 69%, while 26% mention mass explicitly. Another 26% refer to universal gravitation law, but never using formalism. Third question: In 62% of cases the difference between inertial and gravitational mass was also expressed through a characterization of the latter, with respect to the former.

In regard to inertial mass, the category “Newton refers to inertial mass, which is the quantity governing the behaviour of bodies when accelerations/momentum variations (in collisions) are present” is prevalent: 55%. The concept is expressed in a variety of modalities, with most of the answers written in the form: “The ability/property of a body in contrasting a variation in its state of motion / state of rest”. Other frequent answers are either “the ability/property of a body in contrasting a variation in its state of uniform linear motion / state of rest”, or “the ability/property of a body in contrasting the change of state”.

Group question. The relative majority of answering students (12/28) try to give meaning to the concept of quantitas materiae in itself, whereas 8 fix their attention to the circularity problem in Newton’s definition and 8 (different) students just mention this facet of mass, without deepening its meaning. This data should be taken with a special care, because 33% of the whole sample didn’t answer.

A precise distinction between the definitions of gravitational mass (“dynamic” quantity: A precise cause of motion is identified) and inertial mass (“kinematical” quantity: All interactions are considered) was found in 36% only, whilst confusion is present in 57%.

As for inertial mass ($m_i$) we grouped the answers in four not-exclusive categories, from the strictly scientific to the intuitive ones:

1. Constant / proportionality factor in second law of dynamics: 57%;
2. Operational concept, defined by symmetry in interactions, and inertial role of mass: 10%;
3. Concept extended from gravity to every interaction: 19%;
4. Property of the body, which ‘resists’/ ‘opposes’ to something: 36%.

On the other hand, one-half (21/42) of the students consider gravitational mass ($m_g$) as (i) a property mediating/permitting the interaction between bodies or (ii) between masses (16 of these recognize gravitation as a two-body interaction explicitly). 26% highlight mass as (iii) source of interaction, that is active gravitational mass, typically writing ‘property/capacity of generating a force’; 14% consider (iv) $m_g$ involved in gravitational interaction only, while $m_i$ in all physical interactions.

We deduced by variation analysis that categories (i) and (ii) become less important (26 → 18, 11 → 3 students respectively), while (iii) and (iv) become more important (3 → 12 and 0 → 6) passing from the second question to the group question.

Final test. Our final test was composed by four classical and two relativistic questions. C1: « When is mass involved in your everyday life? What are the phenomena in which it is involved? » (see Figure 2), C2: « What physics theories study these phenomena? » (Figure 3), C3: « What do you mean by quantity of matter? » (Figure 4), C4: « What connotations and definitions of mass do you know? » (Figure 5)
Phenomena evoked in familiar contexts were in large part mechanical ones; some students referred to mechanical\textsuperscript{2} quantities associated to mass instead. Besides, the most mentioned theories and physics sectors have been “dynamics” (52%), “mechanics” (40%) and “kinematics” (24%); “relativity” played an important role (36%) as well. On the other hand, there is awareness of the importance of mass in electromagnetism in few students (3/42) and no one is able to contextualize it in familiar phenomena. It is worth noting that, in answers to C1, 7/42 indicated the unique mechanical phenomenon not depending upon mass (in vacuum): Free fall.

The results about quantitas materiae show that this pre-Machian conception of mass is rooted in some minds (6/42 for question C3; 5/42 for question C4). Nevertheless, it is not evoked by the oral answers to the first group question, as verified in the analysis of video recordings, so it’s not so much rooted.

Relativistic part

Answers to the inner questions. From the analysis of the collision process it came out that 7/42 students thought that kinetic energy and rest / internal energy vary in the collision, whilst 4/42 mentioned kinetic energy only (Figure 6). Moreover, 15/42 followed this type of reasoning: Total energy, but not mass, is conserved and kinetic energy varies, so rest energy also do; when $E_0$ varies, mass varies in the same sense\textsuperscript{3}: Mass-energy relationship is valid in variation form as well. These results are however to be taken with a large grain of salt, because most of the students didn’t answer (69% in the 1st case, 64% in the 2nd case).

Final test. R1 - «Does the inertial mass of a body change in function of its energy, apart from the kinetic energy? » (Figure 7)

We found no conceptual reference to the mass-rest energy equivalence in 40% of answering pupils, although our rationale had been brought on the ground of relativistic energy. Our aim was helping students to distinguish between mass as rest energy (its proper meaning) and ‘relativistic mass’. The conceptual reference to mass-rest energy equation is present instead in 43% of cases, mainly implicit or explained in words. Fourteen percent of answers were uncertain, that is enunciations, invocations of a generic relation between mass and energy, not understandable sentences.

R2 - «Relativistic mass is mentioned in many textbooks. Explain what it is» (Figure 8).

A remarkable example of a fourth-category (“mass at relativistic speed”) answer is « That means that mass in motion at very high speed can become energy and vice versa ». The most appropriate answer (III category, “mass depending on speed”) is « Let’s call the relativistic mass $m_r$. We want the classical expression of momentum to be valid with $m_r$ instead of $m$. If we equal the expressions for $p_{rel}$ we obtain $m_v = m_r v$ where $v$ is the particle velocity, and then $m_r = m v$. » Twenty-six percent of the sample uses wrong terminology for this question.

Hypothesis testing. We performed a statistical analysis, namely the calculation of Spearman’s rank correlation coefficient, in order to evaluate if our null associative hypothesis

“\textit{There is no statistically significant correlation between the conceptual reference to mass-rest energy equivalence (mass is } m = E_0/c^2 \text{ in SR) and the presence of the conception of relativistic mass (mass is } m_r = y m \text{ in SR)}\textit{” was supported. Procedures described by Cohen, Manion and Morrison (2007) were followed in measuring the association between two ordinal variables: Let’s call them X and Y. Their values run from 1 to 5, according to the level of presence of conceptual reference to mass-rest energy equivalence (X) and the level of rooting and formalization of “relativistic mass” concept (Y); details are shown in Table 1. The level of significance ($\alpha$) was set; there was no statistical significant correlation found between X and Y ($\rho = -0.2126$, $\alpha < .05$, critical value: $\rho \approx .325$ for $N=37$ couples of data; size effect: $\rho^2 = .0452$). Moreover the probability that 37 measures of two uncorrelated variables yield a correlation coefficient\textsuperscript{4} $r$ if $|r| \geq .2$ is in the interval 22 – 25%.

The previous analysis is useful to clarify statements made in the poster presentation.

\textsuperscript{2} Only mechanical quantities were mentioned, apart from “quantity of matter”, “force fields”, “gravitational field”.

\textsuperscript{3} Notice that these are the same word of Einstein’s first article (1905).

\textsuperscript{4} Even if $r$ is used properly in parametric statistics.
Students’ profiles

The results concerning the five levels of physical representation by Doménech et al. (1993) are shown in Figure 10. Relational level of representation is prevalent: It affects 60% of the sample, as it was to be expected. We found no operational profiles and only one (partially) translational; to be noticed the not-negligible presence of ontological (4/42) and functional (3/42) profiles.

Discussion and conclusions

First Research Question

Students show good capability to understand historical physics texts.

Answer to the group question. As for quantitas materiae, or pupils focus their attention on circularity problem either try to give an (ontological) interpretation.

Nineteen percent seem to be more attracted by negative considerations than by the possibility of a personal revision. In regard to inertial mass, it is understood consistently with Newton’s 2nd law by most students (57%, 24/42). When they have to compare the facets of mass synthetically, 15/42 (different) pupils tend however to fall in rigid patterns related to an action of the body in opposition to motion. Finally, the idea of gravitational reciprocal interaction seems to reduce in favour of an idea of force generated by a source.

Final test. The halving in the number of students with “holistic” vision of mass when changing from everyday phenomena to theories (questions C1 and C2) seems to indicate that “ubiquity” of mass was not rationalized by student having expounded it.

Results on “relativistic mass” (question R2) indicate that students expects a change in the meanings of many quantities in the passage from a theory to another; a conceptual revision is necessary, but it cannot be limited to the semantic aspects, like students do.

In the end, mental representations of mass seem to be strongly affected by learning areas, so it is important to design integrated teaching (Fabri 2007). We noted in particular a local view of the mass in special relativity (SR) in a context defined by speed and a grasping of the concept of mass in SR as limited to a “chapter” of physics.

Second Research Question

Final test. Our students are very good at formalizing, the relationship \( E_0 = mc^2 \) being a remarkable exception in this regard. The concept of “relativistic mass” given by \( \gamma m_0 \) (speed-dependent mass) is integrated in Einsteinian paradigm in 36% of the answering students (14/39), but only 1 student gives the exact definition. This integration is absent instead in 31% (12/39). These results come from the answers to the VI question.

General discussion. Eventually, terminology plays an important role in the proper understanding of mass in relativistic context and in theoretical framing of its conceptual relations with total energy, rest energy and “relativistic mass”. 7/39 wrong answers to the question above are to be ascribed to terminology indeed: We found a mixing of (i) proper \( m_0 \), terminological use, (ii)\( m \), reported to be equal to “the mass in relativity” (\( E_0/c^2 \) as well as “mass in \( E = mc^2 \)”), (iii) mass at relativistic speed, (iv) variation of mass when energy varies.

Eventually, confusion between mass and mole is likely to be due to terminological use of the latter, both as physical quantity and as IS unit, in the right measure of quantity of matter.

Correlation test. The null hypothesis is supported by our ordinal data, so the alternative hypothesis of negative correlation is rejected for our sample. \( P_{37}(|r| > r_0) = 22 - 25\% \) is too high for significance too. We are not allowed instead to say anything about causality. However, when you plot data (see Figure 9), it can be noticed that the top right part of the plot is scarcely populated: The simultaneous understanding and mastery of the two ideas of mass seems not to occur effectively.

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Students' profiles.

First of all, you can see in Figure 10 that mixed categories were found, for students can never be subdivided into entirely separate groups. Most students proved good at understanding and using formal language, often expressing concepts by means of formulas.

However, 5/42 students does not refer to any theoretical framework. Functional level affects 31% of the sample: A theoretical framework is present, but in implicit form in their minds.

References


Table 1. Ordinal variables – from R1 (left) and R2 (right) – for correlation analysis.

<table>
<thead>
<tr>
<th>Student</th>
<th>Level of presence of conceptual reference to mass–rest energy equivalence (ordinal scale)</th>
<th>Level of presence of “relativistic mass” concept (ordinal scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>StudentA</td>
<td>5</td>
<td>1 absent (rest energy/internal energy); 2 weak (mass in Relativity/mass at relativistic speed); 3 medium (energy), 4 strong (mass generically depending upon velocity), 5 very strong (mr = γm₀/varying with reference frame)</td>
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<tr>
<td>StudentB</td>
<td>2</td>
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<tr>
<td>StudentC</td>
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<td>StudentD</td>
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<td>StudentE</td>
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<td>StudentF</td>
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<td>StudentG</td>
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<td>StudentH</td>
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Figure 1. World-line of a generic particle and a light ray in the bidimensional Minkowski space-time (c is light speed in vacuum: Spatial distances are measured in time intervals on the ct axis).

Figure 2. Mass in everyday life: Typologies of evoked phenomena (answers to C1 in the final questionnaire).
Figure 3. Physics theories and sectors concerning the phenomena previously recalled (answers to C2).

Figure 4. Students’ conceptions of quantitas materiae; Other = $N_A$ (Avogadro’s number), density, “mass concentration in a given volume”, number of molecules or atoms or particles in a body (answers to C3).
Figure 5. Facets of mass present in the answers to C4.

Figure 6. Forms of energy varying in a collision between two identical particles (inner relativistic question).
Figure 7. Conceptual reference to mass-rest energy equivalence $E_0 = mc^2$ (R1).

Figure 8. Conceptions of “relativistic mass” (answers to R2).
Figure 9. Ranks correlation (the dimension of each bubble is proportional to the frequency of the corresponding couple of data).

Figure 10. Students’ profiles (worked out by ‘horizontal’ analysis).
Reasoning and Models of Talented Students on Electrical Transport in Solids

Giuseppe Fera, Physics Education Research Unit, University of Udine, Italy
Marisa Michelini, Physics Education Research Unit, University of Udine, Italy
Stefano Vercellati, Physics Education Research Unit, University of Udine, Italy

Abstract

A sample of 40 students, selected from the last two classes of Italian secondary schools to participate in a school of excellence in modern physics, after measuring resistance as a function of temperature of metals and semiconductors and Hall coefficient at room temperature, was engaged in conceptual exploration of contexts related to the nature of charge, voltage, current and electrical resistance. Results highlight that the construction of the connection between macroscopic phenomenology and microscop ic models concerning electrodynamics processes is not only a success in physics, but it is also a possible way to address the widespread and persistent difficulties that students face during the building of the interpretative models.

1. Introduction

In the all school levels (primary, secondary and university) the topics of electrodynamics are in the curricular plans among all the university institution across Europe (Euridyce, 2011).

Research literature highlight the presence of persisting learning knots also in students of secondary schools as concern charge, electric field, potential and the meaning of conductivity (Duit, R. & von Rhöneck, 1998; Mulhall, McKittrick, Gunstone, 2001).

The understanding of the phenomena is closely related to models, analogies, simulations that students hardly integrate into a coherent and comprehensive conceptual framework (Stocklmayer & Treagust, 1996; Wittman, Steinberg, Redish, 2001).

In literature, a wide discussion address the opportunity to adopt a microscopic approach to the phenomenology of electrical conduction (Eylon & Ganiel, 1990; Psillos, 1998; Thacker, Ganiel & Boys, 1999; Chabay & Sherwood, 1999).

In particular, recent works shows how the understanding of the relationship between the physics quantity involved and the electrodynamics phenomenology requires the clarification of the relationship between charge, current, voltage and electric field (Hirvonen 2007; Hart, 2008; Stocklmayer, 2010).

The learning, considered as the conceptual knowledge of these relations, state the problem of the nature of the quantity themselves and in particular the overcoming of the following aspects: 1) conceptual connection between electrostatics and electrodynamics, 2) the role of the electric field and its dynamic relationship with the electric charge, 3) the overcoming of the idea that relations between charges and electric field are local. The addressing of a microscopic model of electrodynamics arises therefore in these terms and not in terms of possible simple descriptive mechanisms or figurative representations useful to memory.

Research question are:

1. what are the conceptual referents of students’ reasoning on the electrodynamical phenomena and how they play an interpretative role?
2. how different activities (simulations, experiments, analogies) promote the integrated interpretation on macro / micro levels and how these can be used in the different contexts?
3. what interpretative role plays a quantum description in continuity with the classical model?
2. Context and method

The experimental intervention was proposed during the Summer School National Modern Physics (Udine, July 2011) organized as part of the project IDIFO3 of the National Plan for Scientific Degrees. It was addressed to 40 participating students selected on the basis of grades in physics from Italian students enrolled in the fourth and fifth classes of upper secondary school (grade 11th and 12th).

The learning path is divided into two phases: Activity 1) a laboratorial exploration of the electrical properties of solids, Activity 2) a seminar concerning models of electrical conduction in solids.

Activity 1: Students perform measurements of resistivity of semiconductors, metals and superconductors with respect to temperature from liquid nitrogen temperature to room temperature and measure the sign and the density of the charge carriers by Hall effect in copper zinc and semiconductors at room temperature.

Activity 2: during the seminar were addressed: the nature of charge, potential, current and electrical resistance; the electrical conduction processes in solids and the dependence of the resistance of metals and semiconductors versus temperature.

The Focus of Activity 1 is on the students’ Lab work for the characterization of the resistivity in the metals and semiconductor samples; in Activity 2 on the conceptual reconstruction of the students’ interpretation of the experimental data on the light of the related learning nuclei.

The students’ reasoning and the ideas on each specific topic of the seminar were collected using personal worksheets from each student.

The analysis of the data collected was done in a qualitative way, organizing the interpretations in profiles of reasoning and different uses of the concepts (Groves et al., 2004).

Activity 1 – Laboratorial exploration

Using USB probe for resistivity versus temperature and Hall coefficient measurements (Gervasio & Michelini, 2009) students quantitatively explore the electrical properties of metals and semiconductors. The measurements of resistivity and Hall effect allow them to obtain information on the sign of charge \( q \), concentration \( n \) and mobility \( \mu \) of charge carriers.

![Scheme of Hall effect](image)

**Figure 1.** Scheme of Hall effect

Defining the Hall coefficient

\[
R_H = \frac{c V_H}{I B}
\]

and measuring \( c, V_H, B, I \) (fig. 1) we find

\[
qn = \frac{1}{R_H}
\]

Measuring the resistivity \( \rho \), it is possible obtain the mobility

\[
\mu = \frac{R_H}{\rho}
\]

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For example, using a sample with $c=0.9\pm0.05$ mm and $B=290\pm5$ G and assuming $q$ equal to the electron charge, students interpolating data as in fig. 4, find the concentration $n=10^{20}/m^3$ of the charge carriers in Ge::P (p-doped Ge) and the sign of the charge result to be positive.

**Figure 2.** Copper resistance versus temperature

**Figure 3.** Ge::P resistance versus temperature
A seminar discussion in form of interactive demonstration (Sokoloff et al., 2007) was held with tutorials cards and monitoring of reasoning. Following topics are addressed:

1. **Electrification.** The electrostatic phenomenology justify the assumption of the charge carriers in the material and the concept of potential difference as the engine of charge transfer (Mossenta e Michelin, 2010)

2. **Current and resistance.** The analysis of measures of voltage versus current in circuits with battery, bulb and wires of different material, length and cross section founds the concept of electrical resistance of a wire

3. **Dependence of the resistance versus the temperature.** The change of the brightness of the bulb while the circuit is submerged of liquid nitrogen recall the trend of resistivity versus temperature of conductors such as Cu and Zn and semiconductors

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4. A microscopic mechanistic model of free electron gas in metals is discussed by Supercomet simulation (http://online.supercomet.no/). In this simulation the motion of negative charges is represented in a lattice of positive ions. In the absence of voltage applied across the wire, the motion of negative charges is random and their displacement on average is zero. By applying a voltage across the wire ordered motion overlaps the random motion and it is detected as current. The (constant) velocity of the ordered motion is called drift velocity. Increasing the temperature of the wire, the oscillations of the positive ions around the equilibrium positions increase in amplitude. Conceptual issues of the Drude model is introduced to students with help of this simulation and it was used to predict the evolution of the resistivity of a metal with the temperature; added values and limits of model were analyzed.

5. The energy band model. Piekala chair energy levels (Golab-Meyer, 1991) is used as starting point of a discussion on the energy levels model of the electronic states and to construct the energy band model by means of the simulation proposed by Dean Zollman (http://phys.educ.ksu.edu/vqm/html/eband.html). The quantum-mechanical model is used to interpret the experimental situations already examined by the students.

The core: overcoming of the classical model

Using the classical model (Activity 2, step 4) shown by Supercomet simulation, students interpret the values of resistivity of many metal conductors, but the Hall effect (fig. 4 and 5) highlights also that the sign of the charge carries in metal could be also positive (as for zinc). This result cannot be justified in the context of the free electron gas model.

The electrical conductivity of semiconductors (fig. 3) is many orders of magnitude smaller than metals. Therefore, the concentration of free carriers in semiconductors is many orders of magnitude below the average values of metals. At low temperatures the behavior of the resistivity of semiconductors is qualitatively similar to the metals (fig. 2): resistance increases with temperature through an almost linear law. On the contrary, the behavior at higher temperatures clearly indicates the need for a new physical interpretation. The quick fall of the resistance shows an exponential dependence of the concentration of free carriers from the temperature. This means that the concentration of free carriers increases with temperature in such a way proportional to the factor exp(−A/kT): this result is consistent with the hypothesis of a mechanism of electrical conduction thermally activated by overcoming a “energy barrier”. These experimental facts require a major change in the microscopic model, which can no longer be built ignoring quantum physics. The free electron model becomes a only intuitive reference, that leaves room for a representation based on assumptions centered on state properties of the carriers.

3. Data and Data Analysis

We discuss here the data referred to Activity 2 step 3, 4 and 5.

As concern step 3, students were asked to predict the change in the brightness of the light bulb when the temperature of the wire is lowered. In agreement with the findings of Wittmann et al. (2002) related to the microscopic processes in the wire, a 5% of students expected that the brightness decreases because “in copper wire cooled electrons moving more slowly”. Furthermore, the increasing of brightness is interpreted by 48% of students with the motivation: “ions of the lattice vibrating less, they hindering less the motion of the electrons”.

Students who answered use the following argumentation in support of their predictions: the thermal agitation increases and so the collision/obstacles for the moving charges increase (43%), more resistant at room temperature (8%), at room temperature the motion of the charges is more disordered (8%), at room temperature the electrons are slowed down by the resistance (8%) at room temperature the particles are more excited (3%), the nitrogen liquid facilitates the transmission of electricity (3%), at room temperature the bonds between electron and nuclei are stronger (3%).

As concern step 4, this qualitative interpretation in terms of “kinetic electron gas in a lattice of ions” is also used by students to explain the observed trend of the resistivity in the copper versus the temperature.
The graph of resistivity versus temperature of semiconductor Ge::P, which have a completely different trend, highlights the limitations of the model but only for 8% of students.

Then the use of free electrons model was deepened for the conduction in metals using the Supercomet simulation. 38% of students recognize that at higher temperatures the thermal agitation of the lattice ions is higher and explains the observed trend in the copper resistance with temperature, but, between them, only 60% relates the increase of temperature with a higher frequency collision with the ion lattice. The 35% recognize that the model cannot be used to explain the changes in the resistivity of the semiconductor with the temperature.

The analysis of the plausibility of the physical properties of charged particles represented in the simulation, sees difficulty in 60% of the students on the particle size and in 70% of the students on the speed of the moving charges. Some alternative conceptions reported by other authors (Wittmann et al., 2002, De Posada, 1997) emerge among the replies: the electrons of conduction are subject to the Coulomb force (3%); the drift velocity is much larger than the one of the random motion (10%).

As concern step 5, students describe the states that the chair can have in terms of potential energy to the floor: 35% recognize the change of the potential energy of the chair, 13% recognize the presence of discrete energy levels of the chair, 5% recognize the change of position of the chair.

The state of a physical system can be described by means of a representation of its energy levels, which can be discrete. This is the case of a ball in a bowl. Only 9% of students classify the states that the ball can take with respect to its energy.

The use of energy band model to interpret the electrical conduction in metals highlights some not-common alternative conceptions: 8% of the students explain the difference between metals and insulators in terms of the width of the gap, 8% do not distinguish the promotion of electrons to high energy level from drift motion, 3% introduce in the model the gravitational interaction and the attraction between the ions of the lattice, while, indeed, the 36% use the model according physical vision. However, the energy band model manifests its explanatory capacity in relation to electrical conduction in the intrinsic semiconductor, in particular as regards the trend observed in resistivity as a function of temperature (descending in the intrinsic zone). Applying the model in this context, 25% of students do not recognize the role of the amplitude of the gap, 13% correctly describes the conduction in the intrinsic zone, but only 5% correctly uses the model to distinguish intrinsic from extrinsic conduction.

4. Conclusions

As concern RQ1, students use macroscopic Ohm’s laws as a conceptual referent to analyze the different current intensity as a function of length / section / material of the wires. They evoke microscopic interpretations, but only 15% refers with awareness the existence of a disordered motion of electrons in a wire at room temperature. The concept of resistance is most often associated with an intuitive idea of opposition to the movement. The presence of these ideas indicates that the reflection at the microscopic level is not activated before the use of the Supercomet simulation.

As concern RQ2, the larger fraction of replies leads back the variation of the resistance of a metal with the temperature to the motion of thermal agitation of the lattice ions, confirming so the validity of the Supercomet simulation. There are some limitations as concern the representation of the correct relationships between the physical properties of particles and the unsuitability to describe the behavior of semiconductors. However, the Supercomet simulation seems to offer students an effective tool for representation of the microscopic world, but there is a need to critically discuss in detail the following aspects: dimensions of electrons; dimensions of atoms, lattice pitch (average distance between two ions reticular first neighbors); concentration of conduction electrons; average speed of conduction electrons; mean free path of the electrons of conduction (average path length of an electron between an interaction with a lattice ion and the next).

As concern RQ3, the introduction of discrete levels using the analogy with the energy levels of a chair helps to overcome the difficulties related to the energy levels model and provides a conceptual tool that all students take to approach the interpretation based on the band structure. This conceptual tool is the basis of the formalism and provides a complete description of the observed phenomena.
More than one third of the students interpret the phenomenology of electrical conduction in metals according to the energy band model; the percentage falls drastically to 5% when they interpret the dependence of the resistance of semiconductor with the temperature in different regions of intrinsic and extrinsic conduction. The complexity of the phenomenon requires to recognize and evaluate the contributions by different physical processes in a global view which connects microscopic models and macroscopic quantities: our efforts continue in this direction.

References


Eurydice, Recommended annual taught time in full-time compulsory education in Europe, online http://eacea.ec.europa.eu/education/eurydice/


The Evaluation of a Basic Training Textbook on Physics With a Method of Entry and Drill for University Students Majoring in Liberal Arts

Katsuichi Higuchi, Department of Psychology and Child Studies, Kobe Kaisei College, Kobe, Japan

Abstract

The author created a basic training textbook on basic physics and chemistry for undergraduate students majoring in liberal arts who want to become elementary school teachers, and used it in our college class in 2010. Students in the class learned to be able to solve almost all problems. They, however, still couldn’t solve some exercises after attending the class. The reason looks that they dislike the work which needs ability to read and comprehend, and feel reluctance in looking up and calculating the answer. This attitude can be applied to “laziness” as Kageyama (2002) mentioned. Only using our textbook can’t solve this critical problem. So, this leads us to a new type of textbook which helps to develop ability to read and comprehend, to do counting problems and to refer a dictionary. Furthermore, some applied problems have to be included in this new textbook for students who are good at math and physics.

1. Introduction

Recently in Japan, it has been pointed out that a lot of students dislike science (For example, Ministry of Education, Culture, Sports, and Science, 2001) as well as math (For example, Nishimura, 1999). This problem is regarded as one of the most important problems in pedagogy, and a lot of researches have been carried out.

In the awareness survey on math and science, for 87 freshmen in 2009 (valid answer 69) at our college, we got the following answers: dislike physics and chemistry, dislike somewhat math and science, neither like nor dislike geometry, and like somewhat biology. We found that they came to dislike science after they came to dislike math. In short, there are some or a lot of students who dislike science because they dislike physics and chemistry with calculation (From here, we call ‘physics and chemistry with calculation’, ‘physics’ or ‘physics with calculation.’) and there are some or a lot of students who dislike physics because they dislike math (Higuchi, 2012). Consequently the rate of students who dislike science may decrease when that of students who dislike physics and math decreases.

Six freshmen study for getting licenses for elementary school teachers, and their favorite subjects are similar to those of other students. It is a serious problem that they who may become elementary school teachers dislike math, physics and, science. In short, we can say that if an elementary school teacher who dislikes physics teaches science, the students will follow the same way.

This is why we created a training textbook on basic physics and chemistry with a method of entry and drill for undergraduate students majoring in liberal arts. We, at the same time, aimed to wipe out their dislike for physics and to improve their scholastic ability on it. Moreover, we aimed the erasing of their dislike for math through solving many calculating exercises on physics. This is because we don’t have enough time to teach them math in the science class.

The textbook was used in science class in our college in 2009 and we analyzed an effect on our students (Higuchi). We got the following results: the textbook was popular among them, their scholarship abilities on physics were improved, and their dislike for physics was reduced, and on the other hand, there remain some exercises in the textbook which most of them couldn’t solve. In this research, we analyze the cause of the latter result and discuss a way for resolving this problem.

This paper is organized as follows. In Sec 2, we introduce the textbook in detail and review its effects. In Sec 3, we analyze exercises which most of them couldn’t solve. We propose a support for a few students who are good at math and science in Sec 4. Sec 5 is devoted to discussion and summary.
2. The training textbook

2-1. The training textbook

We hope that undergraduate students majoring in liberal arts who want to become elementary school teachers learn to be able to solve exercises on basic physics and come to like physics. We have a proverb, ‘Practice makes perfect.’ Kageyama, who had been an elementary school teacher, also emphasizes that elementary school students must practice before understanding.

In Japan, it is unfortunate that recently there is a tendency to blame cramming education as exam study. Is it true that the education with repeating and practicing is bad, and that with understanding is good? We claim that a child first gain a sense of accomplishment, then come to like the contents of the subject and understand the contents as a result after he is forced repeatedly to practice. Kageyama (2002) and Shimada (2009) claim likewise this. We essentially hope that students will improve their personality through challenging experiences such as exercises on basic physics in the textbook.

The features and targets expected through the training textbook are shown in Fig.1.

<table>
<thead>
<tr>
<th>Features</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>A lot of easy calculating exercises on basic physics</td>
<td>Wiping out students’ dislike for physics</td>
</tr>
<tr>
<td>Two types of textbooks for teachers with points and for students with blanks, and PowerPoint files for teaching</td>
<td>Reducing teachers’ burden of preparing classes and concentrating on the class itself</td>
</tr>
<tr>
<td>Only one content in the spread 2 pages</td>
<td>Getting sense of accomplishment</td>
</tr>
<tr>
<td>*Left pages with points and examples</td>
<td>*Right pages with exercises of the value replacement by the examples</td>
</tr>
<tr>
<td>Left pages with blanks for writing on the blackboard on their own</td>
<td>Focusing on the class</td>
</tr>
<tr>
<td>Repeatedly solving exercises</td>
<td>Being accustomed to the contents and getting a sense of accomplishment</td>
</tr>
</tbody>
</table>

During the class, students write on PowerPoint files shown by a projector, and then they solve easy calculating examples and exercises on basic physics. Through this process, they make a challenge by themselves and feel a sense of accomplishment, which are needed in the early stages of learning.

The followings are parts of textbook: Figure 1 is for teachers and Figure 2 for students.
Figure 1. The textbook for teachers

Figure 2. The textbook for students
The following is an example of an exercise on dynamics. ‘When force of 10N press an body which have mass of 2kg and is moving on 2m/s for 10 seconds, how much is its acceleration and how far is its distance?’

In this textbook, there are exercises about ‘spring, lever, and pulley,’ ‘speed, acceleration, and motion,’ ‘heat,’ and ‘electric circuit’ on physics. The textbook covers almost all the fields of basic physics. There are also exercises of ‘gas, aqueous solution and state of matter,’ ‘atom and ion,’ and ‘nucleus.’

2-2. Effects on this training textbook (Higuchi)

We used this textbook in ‘Teaching method of elementary school science’ class. There were six undergraduate students in the class. We investigated students’ impression for the textbook, and their correctness of exercises before classes and after all classes. Here they answered in 5 levels, 1-5. ‘1’ is ‘disagree,’ ‘2’ is ‘somewhat disagree,’ ‘3’ is ‘neutral,’ ‘4’ is ‘somewhat agree,’ and ‘5’ is ‘agree.’

The average of their evaluation was very high score, 4.7, and their impressions for physics were improved (1.4->3.3) and those for chemistry were also improved (2.0->3.2).

Before participating in the course, there 45 were exercises with below 20% of questions answered correctly out of 48 exercises. After classes, there were only 3 exercises with below 20% of questions answered correctly, and 42 exercises with over 80% percent of questions answered correctly.

Through these results, our original purpose, ‘Undergraduate students majoring in liberal arts who want to become elementary school teachers learn to be able to solve basic physics exercises and then they come to like physics,’ have almost been achieved.

3. An analysis for exercises with low percentage of questions answered correctly

As mentioned above, before the class, there were 45 exercises with below 20% of questions answered correctly out of 48 exercises. At last there were 42s with over 80% of questions answered correctly and only 6s with below 70%. We analyzed these 6 exercises. They are as follows. Here, percentages of questions answered correctly are shown in the brackets.

*Exercise 1: Specific heat (0/6 -> 4/6)
  A. Water: 200g, 40 deg C, specific heat 1
  B. Pebble: 60g, 80 deg C, specific heat 5

We mixture A and B. Then calculate Celsius temperature of it.

*Exercise 2: Power consumptions and Calorific values (0/6-> 0/6)

Calculate power consumptions and calorific values for 5 seconds at the resistances in previous section.

*Exercise 3: Solvullity (1/6-> 3/6)

There is aqueous solution with 100g of water with 39.0g of salt. How much does precipitating salt weigh when this is cooled?

*Exercise 4: Neutralizing reaction (0/4-> 0/4)

The 6g of hydrochloric acid neutralizes the 9g of sodium hydroxide solution completely. If the 18g of acid mix 21g of the hydroxide solution, answer which is in excess and how the weight of it is.

*Exercise 5: Electron configuration in atoms (0/4->1/4)

Illustrate electron configuration in boron atom.

*Exercise 6: Chemical formula (0/4->0/4)

Represent neutralization between sulfuric acid and sodium hydroxide solution with chemical formula.
3-1. Exercise 1: Specific heat

The solution is as follows.

We regard the last temperature as \(x\) deg C. Here we suppose 0 deg C as a datum point, then calculate heat above datum point. The heat quantities before mixture are as follows.

Water: \(40 \times 1 \times 200 = 8000\) [cal]
Pebble: \(80 \times 5 \times 60 = 24000\) [cal]

Then the total heat quantity is as,
\[8000 + 24000 = 32000\] [cal]. \ ...(1)

The heat quantities after mixture are as follows.

Water: \(x \times 1 \times 200 = 200x\) [cal]
Pebble: \(x \times 5 \times 60 = 300x\) [cal]

Then the total heat quantity is as,
\[200x + 300x = 500x\] [cal]. \ ...(2)

Because the total heat quantities before mixture is as same as that after mixture, then according to (1) and (2) it follows as,
\[500x = 32000.\] \[x = 64\] [deg C].

This problem cannot be solved only with substituting numerical values for a formula. It is needed that students read the essence from the question sentence and make equations logically in the process of solving. Concretely they have to read precisely and think logically. But students consider these works as “troublesome works.” The reason why two students cannot solve this problem though they had finished studying heat already is not because they don’t understand but because they dislike “troublesome works” and cannot make mathematical equations by reading a question sentence, which is a basic ability of math. It is necessary for such students to practice to solve story problems of the equation on math before using this textbook.

3-2. Exercise 2: Power consumptions and Calorific values

The solution is as follows.

First the answers (numerical values) in p.22 at the textbooks are assigned into a formula as follows.

Power consumption: \(P = 2 \times 10 = 20\) [W]
Calorific value: \(Q = 0.24 \times 2 \times 10 \times 5 = 24\) [cal]

This exercise is very easy because students are needed only to assign values into a formula. Unfortunately, its percentage of questions answered correctly is 0%. What they have to do for solving the question is only to refer the answer shown on another page and calculate easy multiplication of decimal. If they had been forced to open the page and calculate it, they would have managed to solve the exercise. We are going to improve this point next year.

The reason, however, why they don’t open a certain page may be attributed to decreasing chances to consult an English dictionary in junior high schools or high schools as “troublesome work.” Also, the reason why they cannot calculate easy multiplication of decimal is because of decreasing chances to practice calculation in elementary schools, and as a result, they consider the practice as “troublesome work.”
3-3. **Exercise 3: Solubility**

The solution is as follows.

First we should see a table on the last page, and should confirm up to 36.3g salt can be dissolved in water at most. In present, 39.0g salt is dissolved. Then, the amount of precipitated salt is as follows.

\[ 39.0 - 36.3 = 2.7 \text{g} \]

Students cannot solve this exercise only by substituting numerical values for a formula. To solve this easy exercise they should read the contents from the sentence and do very easy subtraction referring to the table on the last page. These works, however, are “troublesome works” for students. The reason why three students can’t solve it is not because they cannot understand a concept of solubility, but because they don’t try to read the contents from the sentence and don’t try to refer the table because of feeling troublesome. We propose they should practice to read contents from sentences and to look up words in dictionary using other textbooks.

3-4. **Exercise 4: Neutralizing reaction**

The solution is as follows.

At first we assume that hydrochloric acid 18g completely neutralize sodium hydroxide solution \( x \) g. Then, \[ \frac{18}{x} = \frac{6}{9}. \] \( x = 27 \text{g} \).

Sodium hydroxide solution is lacking because there is only 21g. Namely hydrochloric acid remains. Then, we assume that sodium hydroxide solution 21g completely neutralize hydrochloric acid \( y \) g. Then, \[ \frac{21}{y} = \frac{6}{9}. \] \( y = 14 \).

There is hydrochloric acid 18g, then, \[ 18 - 14 = 4 \text{g} \]

one remains, and the mixture becomes acid.

We cannot solve this exercise only with substituting numerical values into formulæ. It is necessary for them to try to calculate one requisite amount with fixing amount of the other aqueous solution. The reason why all the students can’t solve is not because they cannot understand a concept of neutralization, but because they don’t try to calculate tentatively because of their feeling troublesome. It is necessary for them to practice simple calculation repeatedly.

3-5. **Exercise 5: Electron configuration in atom**

The solution is as follows.

There are five electrons in boron atom. Two electrons are put on first orbit. The other three electrons are put on second orbit.

The students have studied how to illustrate electron configuration in hydrogen atom, helium atom, and lithium atom. They understand that up to two electrons can be put in the first orbit and up to eight can be put in the second orbit. They should fill the orbit with electrons in order. Because this algorithm is very simple, if they have studied it, they can solve this exercise easily.

However, the only one student can solve it. Though they understood electron configuration, they didn’t try to illustrate them. It is necessary for students to practice to illustrate exercises repeatedly with other new textbooks.
Exercise 6: Chemical formula

The solution is as follows.

One sulfuric acid molecule divides into two hydrogen ions and one sulfate ion. One sodium hydroxide molecule divides into one sodium ion and one hydroxide ion. Therefore one sulfuric acid molecule and two sodium hydroxide molecules neutralize. The chemical formula is as follows.

\[ \text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow (2\text{H}^+ + \text{SO}_4^{2-}) + 2(\text{Na}^+ + \text{OH}^-) \]
\[ \rightarrow (2\text{Na}^+ + \text{SO}_4^{2-}) + (2\text{H}^+ + 2\text{OH}^-) \]
\[ \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} \]

The students have already been taught how to solve an example on neutralizing reaction between hydrochloric acid and sodium hydroxide before they try to solve this exercise. They have also been taught ionization of a sulfuric acid molecule and a sodium hydroxide molecule.

No student, however, solved the exercise. There are two tasks to solve it: description of chemical formula, and calculation of required number for neutralization between sulfuric acid molecules and sodium hydroxide molecules. The former contains “troublesome work” for the students to refer to points in the previous section, and the latter contains mathematical thinking to write the formula and to calculate the number of molecules at neutralization. Thus we can see that the combination of these two works makes them feel dislike this kind of exercises. It is necessary for such students, therefore, to practice consulting a dictionary and trying to calculate repeatedly.

Discussion

We analyzed these 6 exercises with low percentage of questions answered correctly. As a result, we found students tend to dislike “troublesome works.” There are two troublesome works in 4 exercises out of the 6s. One is ‘thinking work’ such as reading contents in a sentence, and the other is ‘just trying to check up and calculate’ it is a serious problem for students to have a habit that they consider these as troublesome works and don’t try to perform them. We presume they cannot solve exercises on physics for this reason and then dislike physics. We may, therefore, reasonably conclude that students who studied physics with this textbook learned to be able to solve calculating exercises of easy physics, and then came to like physics. In addition it is found that disliking ‘troublesome works’ is a cause of their disliking physics and science. Such a students’ disposition corresponds to “laziness” which Kageyama pointed out in his book. Most of the exercises in the textbook are easy because students only have to use substituting numerical value into formulae, but some are slightly complicating. Their lazy attitude becomes a significant obstacle to solving complicating exercises. Hence, in order to solve this problem, ‘training to read sentence,’ ‘training to calculate repeatedly,’ ‘training to consult a dictionary’ as elementary learning are as much necessary as improvement of methods on teaching or introduction of new textbooks. These training should not be carried out in the same way at primary and secondary educations because they who came to dislike physics have studied through such educations. Then, we want to create a new textbook on physics like this targeting three trainings mentioned above.

Further study on it will be carried out in future.
4. Other problem

Of the six students there is one student who had been enrolled in science class at high school. She could solve 71% exercises before the class and 93% after the class. She approves and feels satisfied with this textbook. Her attitude for physics changed from ‘negative’ to ‘somewhat positive.’ Then, our goal has been achieved with the textbook for students like her. If application exercises are added, her satisfaction and effect on using the textbook will be improved. One example of the application exercises is as follows.

*One example of application exercise:

A body of 3kg with initial velocity 19.6 m/s is thrown up. Find the height of the tidemark. Here acceleration due to gravity is 9.8 m/s².

5. Discussion and conclusions

The author created a basic training textbook on physics for undergraduate students majoring liberal arts who want to become elementary school teachers, and taught them with using it. After the class, students’ evaluations for the textbook are very good, and they learned to be able to solve calculating exercises on basic physics in it and then their attitude toward physics was improved. However, there remain some exercises with low percentage of questions answered correctly. In this study, we analyzed in detail the reason why they couldn’t solve these exercises. Then, we confirmed that the students dislike ‘thinking works’ such as ‘reading contents from sentences’ and ‘just trying to check up and calculate’ because they consider those works as ‘troublesome works.’ The attitude like this corresponds to ‘laziness’ as Kageyama mentioned. This problem is serious and is not solved only with using this textbook. Similar kind of textbook targeting solving above three trainings is necessary.

Furthermore, it is clear that application exercises should be included for students who are good at physics and math.

Now, our future tasks are as follows:

*Adding application exercises to the textbook

*Improving students’ lazy attitude and creating new training textbook to solve the problem

Acknowledgement

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References


Assessment of the Effectiveness of the Interactive Engagement Approach in Introductory Physics Instruction at a Japanese University

Michi Ishimoto, School of Environmental Science and Engineering, Kochi University of Technology, Tosayamada-cho, Kami-shi, Kochi, Japan

Abstract

This study examines the learning efficacy of introductory physics in terms of the teaching approach and students’ preexisting knowledge using the Force Concept Inventory (FCI) and Force and Motion Conceptual Evaluation (FMCE). The results indicate the instruction strategy to be by far the most effective contributor to students’ learning of Newtonian concepts. The first year students of a Japanese university were divided into groups based on the teaching approaches they would experience: two groups with a traditional approach and one group with an interactive engagement (IE) strategy. The FCI was administered to half of the students in each group before the first class (pretest) and before the final examination (posttest) for an introductory mechanics course, and the FMCE was administered to the other half of the students in each group at the same time. The pretest and the posttest scores were analyzed based on the following student information: (1) type of instruction as employed in an introductory mechanics class, (2) university mathematics placement test score, (3) type of high school physics curriculum, (4) type of university entrance examination taken (some students are admitted to university based on the recommendation of their high school without having to take an academic aptitude test), and (5) national aptitude examination score. For the two traditional approach groups, the normalized gains on both the FCI and FMCE were about 0.2, whereas the normalized gains of the IE approach group were about 0.4; these results were consistent with those previously found in the United States.

Since the 1980s, Physics Education Research in the United States has developed many instructional methods based on interactive engagement (IE) (Beichner, 2009). These developments have increased faculty awareness of students with poor problem-solving skills and low conceptual understanding (even among students majoring in physics). The use of standard examinations to test physics concepts, such as the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1993), has led to the development of many effective instructional methods (Redish, access December 21, 2011). The majority of faculty members in Japanese engineering and science departments attribute student learning to the individual student’s characteristics, not to the instructional methods. In this study, an IE method that has been shown to be effective in the United States is adapted to a Japanese university class. The efficacy of this method is evaluated with the FCI and the Force and Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1998).

In Japan, high school students are required to complete a science curriculum that includes a range of courses: general science, physics, chemistry, biology, and earth science. They are allowed to choose which of these courses they want to study. Most students who intend to go to university choose courses that will help them obtain higher scores on the university entrance examination. Although the intention of the curriculum is to emphasize student understanding of basic scientific concepts, Japanese high schools focus on the teaching of skills for obtaining high scores on the university entrance examination. More students complete advanced high school chemistry and biology than physics because the university entrance examination score is more predictable for these subjects (i.e., students’ ability to answer university entrance examination questions in biology and chemistry is based to a greater degree on their memorization of facts than on their understanding of concepts). In addition to the university entrance examination, many university applicants are required to take the National Center Test for University Admissions (NCT) (ReaD, access November 26, 2011), which consists of multiple-choice questions, to assess their academic aptitude.

Japanese universities use two types of admission systems to assess applicants’ academic aptitude: the recommendation from the high school system and the university written examination system. The latter system is more likely than the former to make use of the NCT to assess students’ academic aptitude (in addition to the university written examination). Students who are admitted through the recommendation...
system receive notification in the fall of their admission to university. In the months between their notification of admission and their graduation from high school in March, many of these students spend less time studying. By contrast, students admitted based on their written examination have to study hard until close to their high school graduation; on average, these students have higher academic skills than those admitted through the recommendation system.

Kochi University of Technology (KUT) is a mid-sized public university with an engineering division that consists of three schools: the School of Systems Engineering, School of Information, and School of Environmental Science Engineering. The academic aptitude level of the students is average among Japanese universities. In the first quarter of 2011, students (mostly first-year students) in an introductory mechanics course were divided into three classes. Two of the three classes offered 14 traditional lectures (duration of each lecture: 90 minutes) with problem-solving recitations and laboratory work. One of the three classes offered 14 lectures with 7 tutorial recitations using IE instruction. The IE class, in which students studied a workbook by Knight and Andrews (2006), offered peer instruction lectures and tutorial recitations in accordance with the lecture tutorial method. Both the FCI and FMCE were administered to all three classes on two different occasions—before the first class (pretest) and before the final examination (posttest). The scores were analyzed in terms of (1) students’ university mathematics placement test scores, (2) the type of high school physics courses they had taken, (3) the type of university entrance examinations they had taken (recommendation or written systems), (4) their NCT scores, and (5) the type of instruction strategies employed in the introductory mechanics class.

Methods

Students Surveyed

Most students in the School of Systems Engineering had taken advanced high school physics, whereas most students in the School of Information and School of Environmental Science Engineering had not. All students in the School of Systems Engineering and School of Environmental Engineering had taken a university-level introductory mechanics class, whereas less than 20% of students in the School of Information had done so. We divided the students into three classes of around 100 students each. The number of students who completed both the pretest and posttest was 291. Because most of them were first-year students in the first quarter of their studies, the pretest results represent what they learned in high school. The percentage scores for both the pretest and posttest and the average normalized gains were calculated according to the type of class (Table 1). Of the students in the two traditional classes (TR), 80% were enrolled in the School of Systems Engineering and 20% in the School of Information. All students in the IE class were enrolled in the School of Environmental Science and Engineering. Over 70% of students in the TR classes had taken advanced high school physics, whereas less than 50% of those in the IE class had.

Concept Inventory

Two types of concept inventory tests were used to assess students’ conceptual understanding of Newtonian mechanics concepts. The pretest and posttest scores on the FCI and the FMCE were used to assess instructional effectiveness. Half the students in each class took the FCI, and the other half took the FMCE during the same period. The average normalized gains $g_\text{p}$ shown in Table 1 are about 0.2 for the TR classes and about 0.4 for the IE class, which is higher than the lower boundary of the IE class value (0.3) that was previously reported in the United States (Hake, 1998).

The FCI consists of 30 multiple-choice questions with a broader domain of topics, including two-dimensional and a wider application of forces. Students who have taken advanced high school physics may be able to choose Newtonian answers more easily for some questions, namely, those that resemble problems on the university entrance examination. The reliability indexes (KR-20) were 0.87 and 0.88 for the pretest and posttest, respectively. TR classes consisting of more students with advanced high school physics had intrinsically higher scores on the pretest. However, the posttest scores showed little difference among the classes.

The FMCE, which consists of 47 questions in total, is designed to measure student understanding of one-dimensional forces and motion as well as energy conservation. This study used single-number scores (Thornton, Kuhl, Cummings, & Marx, 2009) with 33 full points, which exclude the portion of the energy conservation. Compared to the FCI, the FMCE has a sharper focus to assess student understanding of
Newton’s laws. The reliability indexes (KR-20) were 0.92 and 0.95 for the pretest and posttest, respectively. The FMCE pretest scores were about the same in the three classes. However, the posttest scores were higher in the IE class.

The class distribution of the pretest and posttest scores for the FCI and FMCE are shown in Figures 1(a) and 1(b), respectively. The distribution of TR1 scores shows little change between the pretest and posttest. The distribution of TR2 scores shows a shift to a higher score on the FCI and FMCE. The distribution of the IE class scores shows a whole shift with a large gain, indicating the effectiveness of instruction regardless of the pretest score.

Data and Findings

Mathematics Placement Test

At KUT, a mathematics placement test consisting of 20 multiple-choice questions is administered to first-year students before classes start. Japanese university faculty members expect students with a high mathematics aptitude to perform better in physics. This study investigated the relationship between the mathematics placement test score and the FCI and FMCE scores. As shown in Table 2, students were classified into a low, middle, or high mathematics aptitude group based on their mathematics placement score. In the traditional classes, students with higher mathematics scores had clearly higher scores on both the pretest and posttest. However, in the IE class, no difference was detected in students’ posttest scores on the FMCE, in which some questions included graphs. Students with low mathematics aptitude scores in the IE class earned FMCE posttest scores as high as students with high mathematics aptitude scores in the TR class. In the traditional classes, higher mathematics aptitude scores coincided with higher \( g \), as most faculty members expected. In the IE class, high \( g \) values prevailed in all three groups, and the value was higher than that of any groups of students in the TR classes.

High School Physics Curriculum

Students’ self-reported answers to the added question on the FCI test and FMCE test about their high school physics background are summarized in Table 3. Students who had completed an advanced high school physics curriculum had intrinsically higher pretest scores than those who had not done so. However, their FCI scores were mostly below 18 points (60% mark), which is regarded as being the “entry threshold” to Newtonian physics (Hestenes & Halloun, 1995), and their FMCE scores were below 13 points (40%). Their scores indicate that studying advanced high school physics did not substantially contribute to conceptual understanding. In the TR1 class, the normalized gains were low for both categories, indicating the ineffectiveness of instruction. In the TR2 class, students who had studied advanced high school physics had larger gains on the FCI, indicating that the instruction was better suited for them. However, students without advanced high school physics had no gain on the FMCE. In the IE class, high \( g \) indicate that the instruction was very effective in promoting student learning, regardless of the students’ high school physics background.

Types of Admissions Systems

KUT has two kinds of admissions systems for applicants: the high school recommendation and written examination systems. The process of applying to KUT through the recommendation system occurs in late fall. Students’ admission through the recommendation system depends on their high school recommendation and short thesis examination results. The process of applying through the written examination system occurs in late winter, just prior to high school graduation. Students’ admission through the written examination system depends on their written examination and NCT scores. In general, the level of academic aptitude is lower among students who apply through the recommendation system. These students receive notification of their admission to university a few months before high school graduation. During the months leading up to graduation, they tend to study less and are less likely to write the NCT, which suggests that they have a soft attitude toward studying. As shown in Table 4, their mathematics placement test scores and pretest scores were lower than for students applying through the written examination system. However, their \( g \) in the IE class were as high as those of the students who took the written university entrance examination.
National Center Test for University Admissions (NCT)

The NCT is administered annually to half a million applicants in Japan. Sixty-eight of the 92 students in this study who took both the FCI pretest and posttest reported their NCT physics scores to KUT, as did 52 of the 78 students who took both the FMCE pretest and posttest. The NCT contains well-balanced problems of basic high school physics. Figure 2 shows little correlation between the NCT physics scores and the FCI and FMCE pretest scores, indicating that the problem-solving skills measured by the NCT are not well correlated to the understanding of physics concepts. In addition, there were no correlations between the NCT physics scores and the <g> of the two concept inventory tests, suggesting that the problem-solving skills measured by the NCT did not contribute to the learning of Newtonian concepts either.

Discussion and Conclusions

We found the instruction strategy to be, by far, the most effective contributor to students’ understanding of Newtonian concepts. The IE instruction resulted in large learning gains, regardless of the students’ pre-existing knowledge and characteristics.

The belief among Japanese faculty that students’ class performance depends on their level of preexisting knowledge was consistent with the scores observed in the TR1 and TR2 classes but not those in the IE class. The faculty belief is a reflection of a small learning gain, which means the posttest scores are largely the same as the pretest scores, indicating an ineffective teaching strategy.

References


Table 1. FCI and FMCE (%) scores for TR and IE classes.

<table>
<thead>
<tr>
<th>Class type</th>
<th>No. of students</th>
<th>FCI Pretest score, %</th>
<th>FCI Posttest score, %</th>
<th>FMCE Pretest score, %</th>
<th>FMCE Posttest score, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR1</td>
<td>55</td>
<td>54±2.6</td>
<td>61±3.1</td>
<td>0.14</td>
<td>54 34±2.6 43±3.0 0.14</td>
</tr>
<tr>
<td>TR2</td>
<td>55</td>
<td>52±3.1</td>
<td>62±3.2</td>
<td>0.22</td>
<td>46 35±3.2 47±4.0 0.18</td>
</tr>
<tr>
<td>IE</td>
<td>42</td>
<td>40±2.2</td>
<td>63±2.5</td>
<td>0.40</td>
<td>39 33±2.8 62±3.5 0.43</td>
</tr>
</tbody>
</table>

Table 2. Comparison of mathematics placement test scores and FCI and FMCE scores.

<table>
<thead>
<tr>
<th>Class and math score</th>
<th>No. of students</th>
<th>FCI Pretest score</th>
<th>FCI Posttest score</th>
<th>FMCE Pretest score</th>
<th>FMCE Posttest score</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR1</td>
<td>55</td>
<td>16</td>
<td>18</td>
<td>0.14</td>
<td>54 11 20 0.14</td>
</tr>
<tr>
<td>Low (9)</td>
<td>17</td>
<td>12</td>
<td>14</td>
<td>0.12</td>
<td>24 7 9 0.08</td>
</tr>
<tr>
<td>Mid. (10-15)</td>
<td>25</td>
<td>17</td>
<td>20</td>
<td>0.18</td>
<td>22 12 15 0.12</td>
</tr>
<tr>
<td>High (16)</td>
<td>13</td>
<td>19</td>
<td>20</td>
<td>0.11</td>
<td>8 13 16 0.16</td>
</tr>
<tr>
<td>TR2</td>
<td>54</td>
<td>15</td>
<td>19</td>
<td>0.22</td>
<td>46 12 22 0.18</td>
</tr>
<tr>
<td>Low (9)</td>
<td>19</td>
<td>12</td>
<td>15</td>
<td>0.17</td>
<td>17 7 11 0.15</td>
</tr>
<tr>
<td>Mid. (10-15)</td>
<td>24</td>
<td>17</td>
<td>20</td>
<td>0.24</td>
<td>18 11 14 0.14</td>
</tr>
<tr>
<td>High (16)</td>
<td>11</td>
<td>19</td>
<td>22</td>
<td>0.30</td>
<td>11 13 17 0.20</td>
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<tr>
<td>IE</td>
<td>42</td>
<td>12</td>
<td>19</td>
<td>0.40</td>
<td>39 11 29 0.43</td>
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<tr>
<td>Low (9)</td>
<td>8</td>
<td>9</td>
<td>15</td>
<td>0.30</td>
<td>8 8 18 0.40</td>
</tr>
<tr>
<td>Mid. (10-15)</td>
<td>27</td>
<td>12</td>
<td>20</td>
<td>0.42</td>
<td>24 10 19 0.39</td>
</tr>
<tr>
<td>High (16)</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>0.44</td>
<td>7 10 19 0.41</td>
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Table 3. Comparison of high school physics background and FCI and FMCE scores.

<table>
<thead>
<tr>
<th>HS physics background</th>
<th>FCI (full 30 points)</th>
<th>FMCE (full 33 points)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of students</td>
<td>Pretest</td>
</tr>
<tr>
<td>Without adv. HS physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>TR2</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>IE</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>With adv. HS physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>41</td>
<td>18</td>
</tr>
<tr>
<td>TR2</td>
<td>34</td>
<td>19</td>
</tr>
<tr>
<td>IE</td>
<td>20</td>
<td>14</td>
</tr>
</tbody>
</table>
Table 4. Comparison of admissions system types and FCI and FMCE scores.

<table>
<thead>
<tr>
<th>System</th>
<th>No. of students</th>
<th>Pre-test score</th>
<th>Post-test score</th>
<th>&lt;g&gt; math</th>
<th>No. of students</th>
<th>Pre-test score</th>
<th>Post-test score</th>
<th>&lt;g&gt; math</th>
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</thead>
<tbody>
<tr>
<td><strong>Recommendation</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>24</td>
<td>13</td>
<td>14</td>
<td>0.10</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>0.11</td>
</tr>
<tr>
<td>TR2</td>
<td>21</td>
<td>13</td>
<td>15</td>
<td>0.20</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>0.12</td>
</tr>
<tr>
<td>IE</td>
<td>17</td>
<td>13</td>
<td>17</td>
<td>0.38</td>
<td>10</td>
<td>7</td>
<td>18</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Written exam</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>TR1</td>
<td>31</td>
<td>19</td>
<td>21</td>
<td>0.19</td>
<td>14</td>
<td>13</td>
<td>15</td>
<td>0.10</td>
</tr>
<tr>
<td>TR2</td>
<td>34</td>
<td>18</td>
<td>21</td>
<td>0.24</td>
<td>14</td>
<td>12</td>
<td>16</td>
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<tr>
<td>IE</td>
<td>25</td>
<td>13</td>
<td>20</td>
<td>0.41</td>
<td>14</td>
<td>10</td>
<td>19</td>
<td>0.39</td>
</tr>
</tbody>
</table>

*WCPE 2012, Istanbul, Turkey*
Figure 1(a). FCI score distributions of pretest and posttest for TR and IE classes.
Figure 1(b). FMCE score distributions of pretest and posttest for TR and IE classes.
Figure 2(a). Correlation between NCT physics scores and FCI pretest scores.

Figure 2(b). Correlation between NCT physics scores and FMCE pretest scores.
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Teaching Materials along with History of Science:
Electricity and Magnetism

Masako Tanemura, Faculty of Education, Osaka Kyoiku University, JAPAN

Correspondence concerning this article should be addressed to TANEMURA Masako, Faculty of Education, Osaka Kyoiku University, Minamikawahori-cho 4-88, Tennoji-ku, Osaka 543-0054, JAPAN. E-mail: masako@cc.osaka-kyoiku.ac.jp

Abstract

In physics education, teaching science history offers the educational benefits of kindling students’ interest and deepening their understanding. Science history is important in physics education, but in practice, it remains an introductory topic of a unit. This paper proposes an educational program in which the study content is tailored to the flow of science history. The experiments of Hans Christian Ørsted, André-Marie Ampère, and Michael Faraday are important historical developments in electromagnetic theory and technology that are deeply embedded in the elementary-school to high-school curriculum. Therefore, we reproduced the scientists’ experiments and prepared teaching materials for the experiments from which the students can learn physics while honing their thinking processes. The teaching materials comprise the following five points:

1. A Twitter-like summary
2. Re-creation of the experiences of the scientists
3. An interpretation of different physical phenomena that clarifies their interrelationships
4. Emphasis on experiments and construction of experimental devices
5. The original experimental devices are reconstructed because the principles are more easily and clearly understood, and the devices are simple to fabricate.

Our educational program is for a class of university students who aim to become teachers in elementary or junior high schools. Note that physics phobia among elementary school teachers is becoming a problem in Japan, and there are many university students who have an aversion to physics. The purpose of this educational program is to ensure that they understand physics and learn how to teach the subject well as teachers in elementary or junior high schools.

Furthermore, when our educational program was used for incumbent teachers of elementary schools, the class was praised even by those who were not good in physics. The educational program was verified to be effective through their feedback that they enjoyed the class and that they expressed the hope that their pupils could attend the program; thus, the science could be better understood by following the flow of scientific developments in their chronological order.

1. Introduction

This educational program uses the method of the history of science. This is because we assume that there is a similarity between the way in which a scientist discovers an unknown phenomenon and the way in which a beginning student learns about a new phenomenon to build knowledge. We expect excellent learning results from this educational method in which a student learns physics by correlating historical events instead of merely memorizing them.

For example, Galvani’s discovery of animal electricity led to the invention of the voltaic pile and the discovery of the Seebeck effect. It may also be said that Ohm could discover the basic electromagnetic law because he was inspired by the discovery of the Seebeck effect. In other words, a great discovery can catalyze another great discovery. Physics education could be improved if the treatment of the subject emphasizes the linkage between discoveries.
2. **Twitter-like summarization**

Twitter is a service used all over the world in which one posts a short sentence called a “tweet” that cannot exceed 140 characters. Using this format, we created short summary sentences by attempting to guess the scientists’ thoughts. The advantages of using short sentences are that learners can read them at a glance (easily grasp the full meaning) and that the small chunk of information presented would not detract from the pleasure of reading.

Figure 1 shows the flowchart of the historic experiments that have contributed to the development of electromagnetism. The numbers in the arrow show the imagined tweet of the scientists: (1) Luigi Galvani, (2) Alessandro Volta and Galvani, (3) Ørsted, (4) Ampère, (5) & (6) Faraday, (7) Thomas Johann Seebeck, and (8) Georg Simon Ohm. Table 1 summarizes the imagined tweets of these scientists.
| Table 1 |
|-----------------|------------------|------------------|
| (1) | Galvani @Galvani | in 1780 |
| | I did some more experiments with electric charge and frogs. When I touched an exposed sciatic nerve of the frog with a metal scalpel, I saw sparks and the dead frog’s leg kick as if in life. |
| (2) | Volta @Volta | in 1791 |
| | Galvani @Galvani | That sounds interesting! I will try to repeat and check your experiments on “animal electricity”.
| | Volta @Volta | in 1791 |
| | Galvani @Galvani | I did the experiments and I realized that the frog’s leg served as a detector of electricity. |
| | Galvani @Galvani | No! No! I believe that “animal electricity” comes from the muscles. |
| (3) | Ørsted @Ørsted | in 1820 |
| | I discovered that an electric current produces a magnetic field as it flows through a wire. |
| (4) | Ampère @Ampère | in 1820 |
| | Ørsted @Ørsted | I thought that parallel wires carrying currents attract or repel each other, depending on whether currents are in the same or in opposite directions. |
| (5) | Faraday @Faraday | in 1821 |
| | Ørsted @Ørsted | A year after your discovery of electromagnetism, I invented the first device to convert electrical energy into mechanical motion. |
| (6) | Faraday @Faraday | in 1831 |
| | Ørsted @Ørsted | I thought that if electric currents induce magnetic fields, then magnetic fields should induce electric currents. |
| (7) | Seebeck @Seebeck in 1821  
@Volta I thought that an electric current would flow with only two different metals and heat instead of a damp conductor. |
| --- | --- |
| | Seebeck @Seebeck in 1821  
@Volta I discovered that a compass needle would be deflected when a closed loop was formed of two metals joined in two places with a temperature difference between the junctions. This is a thermocouple. |
| (8) | Ohm @Ohm in 1825  
@Seebeck I did my work on resistance. I initially used voltaic piles, but later I used a thermocouple as this provided a more stable voltage. |
| | Ohm @Ohm in 1827  
@Seebeck I described measurements of applied voltage and current through simple electrical circuits containing various lengths of wire. |
| | Ohm @Ohm  
Maybe someone will call this Ohm’s law. |

3. **Relationship between the flow of science history and each event**

In 1780, Galvani found that when dissecting a frog, the leg of the frog jerked when the metal surgical knife touched it. He thought that animal electricity flowed down the nerves of animals. This was the first-ever discovery of artificial electricity other than frictional electricity. He published a paper in 1791 that became very famous. On hearing this, Volta became interested in the phenomenon and studied it himself. Volta disagreed with Galvani and demonstrated that electricity did not originate from the nerves of animals. He invented the voltaic pile, which is a voltaic cell using two kinds of metals. Seebeck learned about the battery Volta invented and thought that an electromotive force could be developed only if the junctions of the two kinds of metals were in different physical states; he found that an electromotive force developed when the temperatures of the two contacts were different. This is called the Seebeck effect. In addition, Ohm clarified the relationship between the metal’s resistance and the length and thickness of the metal wire by using a thermocouple, which Seebeck had discovered could provide a stable power supply. Using the voltaic pile, Ørsted discovered the magnetic action of electric current by observing the movement of a magnetic needle near the conducting wire. Later, on hearing about this, Ampère found that the N pole of the magnetic needle always turned to the left if the electric current flowed from the foot to the head. This was later called the right-hand screw rule. In addition, he discovered that a force of attraction or repulsion developed between parallel conducting wires owing to the magnetic field of the wires, just as two magnets attract or repel each other. From the magnetic action of electric current that Ørsted discovered, Faraday thought that he could find a way to make a magnetic needle rotate continuously; he designed an experimental setup in which a bar magnet rotated in mercury and another experimental setup in which a wire rotated around a vertical bar magnet in mercury. He called this rotary magnetism. The conversion of electric energy into kinetic energy became the principle of the motor. Furthermore, after learning that a magnetic force was created by an electric current flow, he thought that, conversely, an electric current could be created by a magnetic force. Note that there was a social demand in those days to create and use electric current. After conducting various experiments, he finally discovered electromagnetic induction.

The arrows in the flowchart of Fig. 2 express the relationships between the flow of science history and the scientific discoveries.
4. Educational content and educational significance

(1) Invention of the voltaic pile

Volta became interested in Galvani’s experiment and repeated it himself. He thought that the frog did not have electricity and that electricity was created when the two kinds of metals (surgical knives) were connected through the leg of the frog. He thought that the animal simply acted as a galvanometer. A debate broke out between Galvani and Volta. In 1800, Volta was declared the victor when he invented the voltaic pile. However, clearly the discovery of Galvani contributed to the development of the science of electricity; the term *galvanometer* is derived from his name. In the pile invented by Volta, a cloth after being soaked in saline solution or thin acid was sandwiched between zinc and copper plates.
Figure 3. shows the external appearance of a reconstructed voltaic pile made up of several stacked sets of filter paper sheets that after being soaked in a saline solution were sandwiched between zinc and copper plates. A melody is produced when an electronic music box is connected to this voltaic pile. The experimental setup is simple, and many students are surprised to know that this experiment demonstrates the principle of dry cells, which are today used extensively. Figure 4 schematically shows the structure of a voltaic pile.

(2) Discovery of the Seebeck effect

Seebeck, a German physicist, investigated the voltaic pile using wet paper and thought that simply contact was not enough; the two kinds of metals should touch each other under the then-unknown specific conditions. By connecting bismuth and copper wires on one side and a galvanometer between the other sides of the metal wires, he found that an electric current was produced when he touched the junction between the metals with a finger. He reasoned that the electric current was produced because the junction was heated by the finger and found that an electric current could also be produced when the junction was cooled.

An electromotive force is produced in a circuit when the two junctions between the two metals are kept at different temperatures.

(A) Sb, Fe, Mo, Cd, Au, W, Cu, Ag, Zn, Ir, Rh, Pt•Rh, Pb, Sn, Al, C, Pt, Hg, Na, Pd, K, Co, Ni, constantan, Bi (B)

As shown in Fig. 5, between 0°C and 100°C, an electric current flows from metal A to metal B through the low-temperature contact. Figure 6 confirms that the galvanometer is deflected if you touch one end of a copper–constantan thermocouple. The deflection of the galvanometer increases if one end is heated with a cigarette lighter. In addition, the galvanometer is deflected in the opposite direction if the second contact is heated. In this way, we can understand the Seebeck effect.
(3) Discovery of Ohm’s law

In his experiments, Ohm was troubled to find that the current fluctuates in the voltaic pile when it is used as a power supply. Therefore, he decided to use a thermocouple, which Seebeck had discovered could be used as a stable power supply. A thermocouple was made using bismuth and copper, and as Fig. 7 shows, one end was placed in boiled hot water and the other in water with ice. A stable constant-voltage power supply was obtained in this way. He examined the relationship between the current and the wire length and found that the electric current was inversely proportional to the wire length.

He derived Ohm’s first law in the form of Eq. (1). Here, \( I \) is the electric current, \( V \) is the voltage, and \( R \) is the resistance.

\[
I = \frac{V}{R} \tag{1}
\]

Furthermore, experiments were performed with the cross section, length, and materials (conductivity) as parameters, and it was found that the electric current was proportional to the cross section. Thus, he derived Ohm’s second law in the form of Eq. (2), where \( I \) is the electric current, \( V \) is the voltage, \( \rho \) is the specific resistance, \( \ell \) is the length, and \( S \) is the cross section.

\[
I = \frac{V}{\rho \ell / S} \tag{2}
\]

From Eqs. (1) and (2), he derived

\[
R = \rho \ell / S .
\]

This gives the resistance, which is a measure of the opposition to current flow. Ohm’s achievement was praised, and \( \Omega \) (ohm) was adopted as the unit of resistance.

In junior high school, students are simply asked to memorize an expression called Ohm’s law (\( V = RI \)) to solve simple calculations, regardless of whether they really understand the meaning of the law. The real meaning of Ohm’s law is clarified with this teaching material.

(4) Discovery of the magnetic field created by electric current
When Ørsted demonstrated an experiment in his class to show that the electric current in a wire driven by a voltaic pile could generate heat and light, he observed that a nearby magnetic needle was deflected. He confirmed that the needle was vigorously deflected if the current flowed in parallel with (above or below) the magnetic needle and that the needle pointed in the reverse direction if the direction of the electric current flow was reversed. Ørsted demonstrated that a natural force (electric force) could be transformed into a different natural force (magnetic force). It had been believed that electricity and magnetism were different phenomena to be separately discussed in the separate sciences of electricity and magnetism; the science of electromagnetism was the result of his discovery.

In Japanese elementary schools, pupils learn about electromagnets before learning about the magnetic action of electric current. They examine the poles and perform an experiment to relate the number of coil turns and the strength of an electromagnet; however, they do not learn about the role of electric current in the creation of an electromagnet. They learn about the magnetic field created by an electric current first in junior high school. If we look back at the chronology of scientific development, we realize that the electromagnet was invented after it was discovered that an electric current creates a magnetic field. The teaching in schools is upside down from the standpoint of the sequence in which the discoveries occurred. If students do not know how an electric current creates a magnetic field, how can they understand the principle underlying the creation of electromagnets? This points to a pedagogical problem. Ørsted’s experiment can easily be reproduced as shown in Fig. 8, and it is advisable to carry out this experiment before discussing electromagnets.

(5) Discovery of the right-hand screw rule

Ampère conducted an intense study of the magnetic field created by electric current, a phenomenon discovered by Ørsted. He found that if an electric current flowed from the foot toward the top of the head, the N pole of a magnetic needle always pointed to the left. This is the so-called right-hand screw rule, which states that if a right-handed screw is turned, the direction of movement indicates the direction of current while the direction of rotation indicates the direction of the magnetic field. From then on, the convention was adopted that current flows from the positive to the negative direction. In addition, Ampère found that between the two parallel electric currents (electric wires), a force of attraction appeared if the directions of the parallel electric current were the same, and a force of repulsion appeared if the directions of the parallel electric current were opposite.
Figure 9. shows an experimental setup to demonstrate the right-hand screw rule. Many students were impressed by the experiment. Though they learn about this rule in junior high school, very few students perform the experiment. Many university students forget the rule, probably because they learnt about it only through the pictures and figures in a textbook, without any practical experience.

(6) Discovery of electromagnetic induction

Faraday tried to make a magnet turn continuously instead of just being momentarily deflected by an electric current, which was the effect Ørsted had discovered. He placed a bar magnet, as shown in Fig. 10 (left), in a container full of mercury from the top of which a magnetic pole protruded. The experimental setup allowed the magnet to turn around the central axis of the container when an electric current flowed through mercury. In addition, in another experimental setup, a bar magnet was placed at the center of a container with mercury, as shown in Fig. 10 (right), and when an electric current from the copper wire flowed through a wire dropped down from above, and then through the mercury and the base electrode at the lower part of the container, the wire turned around the magnet.

Figure 10. shows the experimental setup for Fig. 10 (right). Figure 11 shows the experimental setup for this unipolar motor, which is made with an aluminum wire, a magnet, and a dry cell; the device is so simple that even an elementary schoolchild can fabricate it.

Faraday thought that “we should be able to get an electric current from magnetic force if we can produce magnetic force from an electric current” and succeeded in an experiment to produce an electric current in 1831. As shown in Fig. 13, two sets of coils are wound around a circular ring of iron; one coil is connected to a battery, and a magnetic needle is placed above the conducting wire connected to another coil. When an electric current flowed, the magnetic needle was deflected, indicating current flow. However, the needle immediately returned to zero. When the current was stopped, the magnetic needle momentarily deflected in the opposite direction and immediately returned to zero. In another experiment, he found that the deflection of the galvanometer increased...
in proportion to the speed with which the magnet was brought closer to or farther from the coil. He announced Faraday’s law of induction at the Royal Society of London for Improving Natural Knowledge, also known as the Royal Society.

Faraday could only produce a momentary electric current by electromagnetic induction. He then invented the world’s first generator using Arago’s rotating disk. His experimental setup was actually aimed at clarifying the principle of the disk. Still, he attained his goal and succeeded in “(steadily) producing an electric current from magnetic force.”

The discovery of Arago’s rotating disk was catalyzed by the improvement of the compass. He found that the magnetic needle rotates when the base copper plate was rotated and that the copper plate rotated when the magnetic needle was rotated.

Figure 14 shows Faraday’s generator (Faraday disk), and Fig. 15 shows Arago’s rotating disk.

5. Discussion and conclusions

Using this teaching material, I took a class for incumbent elementary school teachers. They thought that the best part of the class was the fabrication of Faraday’s motors, followed by the voltaic pile with copper and zinc, which could be fabricated easily; some of the teachers said that they hoped to use the material in their classrooms. Also, many teachers showed interest in the thermocouple. Many said that it was the first time they were learning about the Seebeck effect and appreciated the experiments demonstrating that an electromotive force is produced by a temperature difference. Furthermore, there was a tacit opinion that simplicity of the handmade experimental devices gave them the confidence that they could use them in their own teaching. The general impression was that it is instructive to perform experiments in the sequence in which they occurred in history. In addition, there was an opinion that the summarization in Twitter style was good because of the ease of understanding.

By simply reproducing the experiments at the time of the discoveries in a chronological order, the teaching materials proved effective in demonstrating and teaching the essential concepts of physics.

References


Michael Faraday (1844). Experimental Researches in Electricity

Effect of Indigenous Knowledge in a Physics Curriculum on Pupils’ Attitudes Towards Physics

Aguiar Baquete, Diane Grayson, and Inocente Mutimucuio, Faculty of Education, Eduardo Mondlane University

Diane Grayson, Inocente Mutimucuio, Faculty of Education, Eduardo Mondlane University

Correspondence concerning this article should be addressed to Aguiar Baquete, Faculty of Education, Eduardo Mondlane University, Main University Campus 257. aguiar.baquete@uem.mz

Abstract

In education, attitudes work as an internal factor that guides pupils’ actions towards certain subject matter. Consequently, it is one factor for prediction of pupils’ achievement. Although understanding physics is fundamental to understanding the world around us, results of research carried out worldwide have shown that pupils’ success in physics is often lower than in other subjects. This paper reports on the effect of incorporating indigenous knowledge related to thermal phenomena concepts on Grade 9 pupils’ attitudes towards physics. Indigenous knowledge (IK) related to physics concepts was incorporated into physics teaching materials developed by the researchers to serve as a bridge between Western and non-western thinking and reasoning. The sample comprised 216 pupils (135 girls, 83 boys) from a secondary school in Chókwé. Grade 9 was chosen because this is when pupils learn thermal phenomena, one of the topics for which physics-related IK had been identified in an earlier study, during interviews with senior citizens. An experimental approach was used, involving a pre-test, teaching intervention and post-test with experimental and control groups. The attitudes questionnaire consisted of Likert scale type multiple-choice questions. The contextualized teaching materials used in the intervention were based on IK and pupils’ everyday environment, and the teaching was inquiry-based. Comparison of responses on the attitudes questionnaire of the experimental group and control groups suggests that the teaching intervention had a positive effect.

Key words: Indigenous knowledge, physics curriculum material, pupils’ attitude, teaching strategies

Each society has its own culture, which forms the basis of their thinking (Bryce & Blown, 2006; Higgs, 2006; Snively & Corsiglia, 2001). “Western science”, which is taught in educational institutions, from schools up to universities, is related to Western culture or Euro-American Culture (Aikenhead & Ogawa 2007). Literature reveals that the science/physics learning achievement in many developing countries is strongly influenced by learners’ environment and their attitudes (Adesoji 2008; Gautreau & Binns 2012; Khan & Ali 2012). The former is the source of previous knowledge and the latter reflects the motivational stage, the state of readiness of the learner to react to a situation. The term “developing countries” is associated with poor and non-western countries. In this paper, knowledge from developing countries is labelled indigenous knowledge (IK), or indigenous knowledge and technology (IKT). Indigenous knowledge and technology as socio-cultural knowledge is acquired as a product of multiple interactions of the learners and the environment in which they live, which could be family, ethnic, and/or social group (Das Gupta, 2011; Sharma; Bajracharya & Sitaula, 2009). In the literature on science education the concept attitude encompasses different perceptions. For instance, attitude towards science/physics is related with interest or feeling towards science/physics (Yara, 2009). Others perceive it as a learned predisposition to evaluate something, be it a proposition, a person, object or action (Broggy & McClelland, 2008; Gardner, 1975 quoted by George 2000). Thus, in any situation of learning science, including physics, it is possible to identify individual pupils who generally seem to have a more positive or less positive attitude towards science/physics. For Khan & Ali (2012), attitude is connected with individual likes or dislikes towards something and is an individual temperament, a way to look at things which can attract or not, or even repulse. For George (2000) attitudes are concerned with the way of individual thinking, acting and behaviour which can be stated through favourable or unfavourable reaction to things, places, events or ideas, which are strongly influenced by the culture and beliefs of the learner. It is evident that there is a range of percep-
tions associated with the concept attitude. However, its role in education is central because it is one of the key factors that influence the effectiveness of teaching and learning. Thus, attitude is one predictor of student achievement.

Concerning IKT, although there is a long debate about the definition, nature, epistemology and status of IKT that could be incorporated in formal education, many researchers perceive IKT as a common way to label all valuable, alternative ways to organize knowledge, technology and social experience that is different from Western scientific knowledge or Euro-American knowledge (Bajracharya & Sitaula 2009; Forrest 2000). As educators, what we need to recognize and highlight is that indigenous knowledge is a cumulative body of knowledge, practices and representations maintained and developed by people with extended experiences of interaction with the natural environment; based on sophisticated sets of understandings, interpretations and meanings which are part and parcel of a cultural heritage that encompasses language, symbols, designation and classification systems, resource use practices, ritual, spirituality and worldview (Charles Royal 2002; Raza & du Plessis, 2001). Furthermore, our challenge as science educators is to emphasize the socio-cultural usefulness of any indigenous knowledge.

Relating IKT and education, one of the main objectives of the latter is to pass on social-cultural values, including IK, from senior generations to youths as a way to socialize the new generations with their culture. As for its label, in this study all non-western knowledge or science, independently of its origin, such as, ecological knowledge, indigenous knowledge system, African science, traditional knowledge, local knowledge, familiar knowledge, and so on will be called indigenous knowledge.

As for formal education the inclusion of previous knowledge based on indigenous knowledge and pupils’ environment should contextualize the science classroom and, consequently, bring pupil’s background knowledge into the classroom, which should help to relate their culture and scientific culture. Science/physics taught in conjunction with local traditional knowledge brings not only a sense of place, for non-western pupils, but also helps to make science more universal and less strange to pupils (Kasanda, at al., 2005). In addition, the contextualization of teaching materials and the science classroom should give pupils opportunities to develop critical thinking and promote positive attitudes, consequently stimulating their participation in the classroom.

Concerning achievement in science, a range of literature links achievement with positive attitudes towards subject (Anwer, Iqbal & Harrison, 2012). Other studies relate success at school with the school context, e.g., a good teaching and learning environment and involvement of parents and teachers’ experience (Yara, 2009).

In trying to address these and other concerns related to pupils’ performance, there has been considerable research carried out in different countries, some of which is showing the pertinence of incorporating pupils’ previous knowledge, including pupils’ environment, in the science/physics classroom (Coştu & Ayas, 2005, Denzin & Lincoln, 2011). Others suggest that curriculum innovation in non-western countries should not only emphasize Eurocentric philosophy during science curriculum design, but also contextualize the curriculum materials through the incorporation of students’ environment and IKT (Vos, Devesse, & Pinto, 2007). The statements above raise three ideas: (i) the need to explore indigenous knowledge in science teaching and learning; (ii) the idea that the inclusion of indigenous knowledge and pupils’ environment should stimulate students’ interest towards science/physics and, consequently, increase their performance in the classroom and (iii) the existence of factors which interfere with pupils’ attitudes. From these points of view, determining pupils’ previous knowledge, their environment and knowing the indigenous knowledge that they hold become an important starting point in designing a suitable learning environment and developing new teaching strategies to minimize the preconceptions and promote appropriate connections between different worldviews (Baquete, Grayson & Mutimucuo, 2009). Additionally, Yara, (2009) argues that physics as a subject requires a commitment on the part of both teachers and students if they want the process of teaching and learning to be effective, because the teaching and learning of physics is not just a process of transfer from the teachers, and memorization of concepts and formulas by learners, but it is a process of scientific knowledge construction based on scientific understanding of phenomena and concepts.
According to science education literature the concept attitude encompasses different perceptions and is related with: (i) interest or feeling towards science/physics (Yara, 2009), (ii) individual likes or dislikes towards something and is an individual temperament, a way to look at things which can attract or not or even repulse (Khan & Ali, 2012), (iii) individual ways of thinking, acting and behaviour which can be stated through favourable or unfavourable reaction to things which are strongly influenced by the culture and beliefs of the learner (George, 2000). As a result, in any situation of learning science, including physics, it is possible to identify individual pupils who generally seem to have a more positive or less positive attitude towards science/physics.

Thus, the role of attitude in education is central because it is one of the key factors influencing the effectiveness of teaching and learning. Consequently, it is one possible reason for good pupils’ performance in the classroom. Therefore, attitude is one predictor of pupils’ achievement.

Other findings from the literature stress the role of the school environment, the teacher, textbooks and students’ attitudes whether positive, neutral or even negative, for good performance in the classroom (Prokop, Tuncer & Chudá, 2007). Obviously students’ background, such as the family as source of previous knowledge, plays an important factor in their positive or negative attitudes towards science/physics (Ipsos Mori. Social Research Institute, 2011).

In this study we investigated the effect of incorporating indigenous knowledge and technologies and pupils’ previous knowledge into Grade 9 physics curriculum materials on students’ attitudes to physics as well as the effectiveness of that material on teaching and learning physics concepts. In this paper we address the research questions: (i) What are students’ attitudes to learning physics before instruction? and (ii) What is the effect of using contextualized materials and inquiry-based learning on students’ attitudes to learning Physics?

**Methodology**

As mentioned early the sample for the study was comprised of 216 Grade 9 pupils (134 girls, 84 boys) from a Junior Secondary School in Chókwé - Mozambique, the same region in which the in-depth and semi-structured interviews with senior citizen on indigenous knowledge related to physics concepts were reported in a previous study (Baquete, Grayson and Mutimucuio, 2009). The sample was divided into two groups, control and experimental, comprised of 108 (67 girls, 41 boys, range age 13-17, and 65 girls, 43 boys range age 13 – 22, respectively), whose demographic distribution of age and gender are presented in Tables 1 and 2.

**Table 1. Experimental group demographics**

<table>
<thead>
<tr>
<th>Age</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>≥17</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls</td>
<td>02</td>
<td>16</td>
<td>15</td>
<td>24</td>
<td>10</td>
<td>067</td>
</tr>
<tr>
<td>Gen.</td>
<td>Boys</td>
<td>01</td>
<td>09</td>
<td>09</td>
<td>14</td>
<td>08</td>
</tr>
<tr>
<td>Blank</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>Tot./Frequency</td>
<td>03</td>
<td>25</td>
<td>24</td>
<td>38</td>
<td>18</td>
<td>108</td>
</tr>
<tr>
<td>Percent (%)</td>
<td>02,8</td>
<td>23,1</td>
<td>22,2</td>
<td>35,2</td>
<td>16,7</td>
<td>100</td>
</tr>
</tbody>
</table>

**Table 2. Control group demographics**

<table>
<thead>
<tr>
<th>Age</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls</td>
<td>12</td>
<td>26</td>
<td>18</td>
<td>09</td>
<td>065</td>
</tr>
<tr>
<td>Gen.</td>
<td>Boys</td>
<td>04</td>
<td>11</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Blank</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>00</td>
<td>000</td>
</tr>
<tr>
<td>Tot./Frequency</td>
<td>16</td>
<td>37</td>
<td>32</td>
<td>23</td>
<td>108</td>
</tr>
<tr>
<td>Percent (%)</td>
<td>14,8</td>
<td>34,3</td>
<td>29,6</td>
<td>21,3</td>
<td>100</td>
</tr>
</tbody>
</table>
A convenience sample was used because, in order to avoid disrupting the normal running of the school programmes, the researchers worked only with those classes whose teacher had indicated would compensate the time made available for this research by means of extra lessons. Concerning the socioeconomic status of the respondents, the majority of them come from low to middle class families, whose activities consist mainly of farming, informal employment and public services. Grade 9 was chosen because the topic related to thermal phenomena, which is introduced in this grade and was one of the most mentioned by senior citizens, through different examples of thermal phenomena or events, such as the production of African beer, and preference for using clay pots and wooden spoons for cooking rather than metal utensils. These results were obtained through in-depth and semi-structured interviews and have been reported in Baquete, Grayson and Mutimucuio (2009).

The research used an experimental approach following a pre-test, teaching intervention, post-test with experimental and control groups. The questionnaire used in the pre and post tests consisting of Likert scale type questions was inspired by other instruments used to investigate pupils’ attitudes towards science (Demirci, 2004), with strongly agree (1) up to strongly disagree (5) statements. Each statement was followed by a space in which pupils had to fill in a justification of their choice.

A pilot study involving a small group of pupils was conducted in order to assess, among other elements, the suitability of the time needed to fill in the answers, the language and the contextualization of the questions. The final questionnaire was organised in four categories namely (i) intrinsic ability (questions 1 and 3); (ii) relevance (questions 2 and 7); (iii) nature (question 6) and (iv) interest (questions 4, 5, 8 and 9). The reliability factors of the instrument were tested using Cronbach’s Alpha, producing a value of 0.70. A peer correlation value among pupils’ responses varied between 0.67 and 0.90 meaning that both the questionnaire and pupils’ responses are valid.

Concerning the teaching intervention, the two groups, experimental and control, were taught by the same teacher, had the same time allocation (45 minutes per lesson) and the same topic. The only difference between them was the use of the contextualized teaching materials by the experimental group and the use of an inquiry approach based on an analogy and cognitive conflict (POE) strategies. The teaching materials incorporating IK and pupils’ environment, in this study called contextualized teaching material, were developed by the researchers. The school physics teacher who gave the lessons was trained by the first researcher and during the teaching intervention the first author also participated as observer.

**Results**

Table 3 shows the post-intervention mean scores and standard deviation (P-IMSD) of the statements for the experimental and control groups on the attitudes’ questionnaire, where 1 is ‘strongly agree’ and 5 is ‘strongly disagree’.

The responses showed that, in general, pupils who had lessons with contextualized teaching materials based on inquiry approach had more positive attitudes towards physics than pupils from the control group.

Nonetheless, in order to refine the pupils’ responses according to the goals of the study the effect of the contextualized teaching materials to their attitudes was done via a descriptive statistic mean and standard deviation in both groups as shown in Table 3.

Further, beside a single analysis per question, it is useful to compare the qualitative responses of pupils in each of the four categories. Thus, the pupils’ responses were coded in the following way: Sx-P1-E and Sx-P2-C, where S means pupil, x means a number sequence in which each questionnaire was processed, P1 means pre-test and P2 post-test, E experimental group and C means the control group. Below are the qualitative results per category, analysed together with quantitative data from tables 3 and 4.
Table 3. P-IMSD of the responses to the attitudes questionnaire

<table>
<thead>
<tr>
<th>Statement</th>
<th>Categories</th>
<th>Exper. Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Intrinsic ability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 - I think that anyone can be a good physics pupil if he or she works for it</td>
<td></td>
<td>1.92</td>
<td>1.13</td>
</tr>
<tr>
<td>Q3 - Only bright Mathematics’ pupils can do well in Physics</td>
<td></td>
<td>3.00</td>
<td>1.68</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 - Physics is related with my own everyday life</td>
<td></td>
<td>1.89</td>
<td>1.25</td>
</tr>
<tr>
<td>Q7 - Physics subject has little relation to my everyday life</td>
<td></td>
<td>3.46</td>
<td>1.60</td>
</tr>
<tr>
<td><strong>Nature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6 - It is possible to explain physics ideas without mathematical equations</td>
<td></td>
<td>2.70</td>
<td>1.74</td>
</tr>
<tr>
<td><strong>Interest</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4 - I find Physics interesting</td>
<td></td>
<td>2.05</td>
<td>1.34</td>
</tr>
<tr>
<td>Q5 - I like to discuss Physics with other pupils</td>
<td></td>
<td>2.62</td>
<td>1.56</td>
</tr>
<tr>
<td>Q8 - Currently, I like Physics very much</td>
<td></td>
<td>2.82</td>
<td>1.65</td>
</tr>
<tr>
<td>Q9 - Next year I plan to take Physics subject</td>
<td></td>
<td>2.86</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Table 4 shows the number of pupils in each group who strongly agreed or agreed with each statement, before and after the intervention. The results for both the pre-test and post-test are shown, together with the gain in the number of positive responses.

Table 4. Number of pupils who strongly agreed or agreed with each statement in the pre and post test for the experimental and control groups.

<table>
<thead>
<tr>
<th>Statements</th>
<th>Categories</th>
<th>Frequencies of agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Experimental Group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre</td>
</tr>
<tr>
<td><strong>Intrinsic ability</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 - I think that anyone can be a good physics pupil if he or she works for it</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Q3 - Only bright Mathematics’ pupils can do well in Physics</td>
<td></td>
<td>57</td>
</tr>
<tr>
<td><strong>Relevance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 - Physics is related with my own everyday life</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Q7 - Physics subject has little relation to my everyday life</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td><strong>Nature</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6 - It is possible to explain physics ideas without mathematical equations</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td><strong>Interest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4 - I find Physics interesting</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>Q5 - I like to discuss Physics with other pupils</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Q8 - Currently, I like Physics very much</td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>Q9 - Next year I plan to take Physics subject</td>
<td></td>
<td>46</td>
</tr>
</tbody>
</table>

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Discussion and conclusions

The discussion is conducted along the four categories of the questionnaire.

Intrinsic ability

This category deals with questions related to pupils’ intrinsic ability, questions 1 and 3. For question 1 stating that ‘I think that anyone can be a good physics pupil if he or she works for it’, table 4 shows that 7 pupils in the control group who had shown a positive attitude in the pre-test shifted their answers, within the Likert scale in the post-test. Consequently, the percentage of positive responses dropped 7,4%, while in the experimental group the gain was from 90 to 93. Looking at some pupils’ justifications for their answers we found the following example:

S30-P1-C: I agree. If you study well ... and follow the teachers’ recommendation and exchange ideas with colleagues you can do well in Physics.

After the intervention, this pupil changed his opinion, as shown below.

S30-P2-C: Physics is difficult ...you need to know the formulas and theory...is not easy if you remember one thing you forget other, you need to be a good pupil.... teachers also give different assignment from what they taught during classes

Another pupil who held two different opinions, before and after the intervention, is pupil S35.

S35-P1-C: Physics is a difficult subject but if you study properly...do homework, have a study group on weekend... you can get good marks

S35-P2-C: ...I disagree ...only good pupils can be good in physics...I do my homework...I have a study group ...after a test I’m sure that I did well...but I’m not getting positive marks....physics is difficulty...is easy for good pupils

These pupils’ justifications suggest that their responses are strongly influenced by marks after assessment. Also, it is interesting to see that, after intervention, pupil S30-P2-C suggests that there was no relation between the content taught and the content assessed.

As for the question 3, reading ‘Only bright Mathematics’ pupils can do well in Physics’, table 4 shows a decrease of pupils in the experimental group holding that only bright pupils can do well in physics. Here are some examples of justifications, given by pupil S5, before and after the intervention:

S5–P1-E: To explain phase change you need to calculate heat, to change scale you need formula ...if you are not good in mathematics you can’t be good in physics.

S5-P2-E: Yes, I agree that anyone can be a good pupil in physics even if is not good in mathematics... for instance to explain how clothes dry is not necessary Mathematics.

A similar change of attitude, after intervention, was shown by pupil S11.

S11-P1-E: Physics is difficult ...you need to know the formulas ...is not easy...you need to everything... you need to be a good pupil....

S11-P2-E: ...; there are many phenomena that we can explain without Mathematics...for instance the drops of water around the surface of clay pots...to define heat is not necessary any formula ...you can understand physics even if you are not good pupils in mathematics.

Looking at the kinds of objects mentioned in these examples, we can infer that the teaching material had a effect in the change of attitudes of these pupils.

Relevance

This category helps us to understand why physics is relevant to pupils’ everyday life. In question 2, table 4 shows that the gains in both groups, experimental and control, are high and the same, 41. The results suggest that the contextualized teaching materials did not have any greater effect in pupils’ attitudes in
this question, as compared to the more traditional way of teaching without consideration of the context. Nonetheless, if we compare the means and SD in table 3 between responses in both groups, we find that the values of the means are 1.89 against 2.20, and SD=1.25 against SD=1.76, in the experimental and control groups, respectively. These values show that, although the gain was the same, the spread of values in the experimental group is lower than in the control group, meaning that the contextualized teaching materials affected pupils’ responses. One example of pupils’ justification is shown below, taken from the experimental group.

S17P1E: Physics is science...only last year I start to learn Physics

S17-P2-E: Yes physics is related to my life, according with our physics teacher cars are able to stop due friction force between the wheels and the road... in hospitals they use thermometers...Here in Chókwé in the morning is very cold and we wear jackets.

Similar justifications were also found in the control group, as is illustrated by one example taken from pupils S50.

S50-P1-C: I don’t know

S50-P2-C: We discussed in the class the velocity of cars, temperature of the human body, conductivity ...we get burned because spoons get hotter when immersed in hot tea...yes physics is related to my everyday life

For question 7, stating that ‘physics subject has little relation to my everyday life’, we found that the gain was positive, 17 from experimental group against 13 from control group.

The justifications given in support of their options were similar to those also given in question 2. These results may suggest that most pupils see the relevance of physics to their everyday life. However, the issue of developing appropriate attitudes towards may be strongly associated with other factors.

**Nature**

This category is composed only by question 6, stating that ‘It is possible to explain physics ideas without mathematics equations’. Table 4 shows a significant change of opinion between control and experimental groups after the intervention. The examples given below illustrate the justifications given by both groups, before and after the intervention.

S40- P1-E: ...is not possible to learn physics without mathematics, I have never done any physics test without problem solving questions

S40-P2-E: Physics is interesting...we can explain many phenomena without using Mathematics...for instance why murrigwé (water container) has drops of water around its surface...why we have fogs in the morning in the farms,...some aspects of physics can be explained without writing equations.

A similar justification given after the intervention, was that of pupil S70

S70-P1-E: I disagree completely...is not possible... how to talk about velocity without Mathematics?... Even to show distance we need a formula or mathematics knowledge

S70-P2-E: ...there are many phenomena that we can explain without using mathematics expressions, for instance how the clothes dry...how fog is formed or why the fog disappear when the sun rises...

As it can be seen from these examples of pupils’ justifications of their options, it seems that the contextualized teaching materials had a major effect on pupils’ attitudes. The term ‘why’ they use when they admit explaining physics phenomena without mathematics equations calls upon qualitative statements which can fully describe physics phenomena without necessarily using mathematical algorithms.

S28- P1-C:... Is not possible I never do physics test without problem solving...and problem solving has high marks...if you miss the formula or forget it you will have low mark.

S28-P2-C: I am not sure...but it is possible... the problem is what we discuss in the classroom with the teacher... many times involves a formula or a equations...
When contrasting the examples given by pupils S40, S70 and S28 one can see that the pupils' justifications of the control group showed that contextualized teaching materials, incorporating IK and pupils’ environment, promoted the use of words such as fogs and clothes in the explanation of physics phenomena, while the example of control group lacks of such words.

**Interest**

This category had four questions, namely questions 4, 5, 8 and 9 related to interest.

In question 4, reading ‘I find Physics interesting’, the gain in the experimental group was 30 points against 10 of control group. Some pupils’ justifications were:

S45-P1-E: Physics is nice...but you need to memorize many things, formulas, thermal scales... from Celsius to Fahrenheit...

S45-P2-E: Physics is interesting because we talk about things that exist and happen in our daily life ...unfortunately most of these things that we learn in the class we cannot find in own books... and not all teachers teach physics in the same way... S12-P2-E: I don’t like physics... we need to memorize a lot of formulas...

S12-P1-E: ...well ...I think Physics is interesting ...now I know that heat, condensation and cooking are related to physics...but there are problems with the lack of teaching materials ...

It can be seen that although some pupils of the experimental group say that they find physics interesting, they raise a problem related to the lack of teaching materials such as books which could help them deepen their interest in the physics subject.

For question 5, ‘I like to discuss Physics with others pupils’. Pupils’ responses indicate their commitment in seeking explanations from colleagues when they face difficulties in some topics. As it can be seen from table 4, this was the case in both groups and also before and after the instruction.

As for question 8, stating that ‘Currently, I like Physics very much’, table 4 shows that both groups had almost the same attitude scores before intervention. However, after it the gain in the experimental group was 15 against 1 of the control group. Some comments are:

S78-P1-E: I disagree, I don’t like Physics we write many assignments containing physics names and equations...but we don’t see the called things... S78-P2-E: I like physics because in physics we discuss things that we are dealing in our daily life...for instance we learned and measured velocity, , heat and temperature...

S22-P1-E: I don’t know this is my second year learning physics...

S22–P2-E: I like to learn physics because it helps me to understand many things... how the clothes dry...the difference between heat and temperature...conditions for phase change...

The difference in gain of attitude scores of the experimental group may be attributed to the contextualized teaching materials incorporating IK and pupils’ environments.

**Conclusion**

Results indicate that, in general, the contextualized teaching materials which incorporate IK and pupils’ environment promote positive attitudes towards physics.

Also, we can conclude that before instruction, many pupils held negative attitudes as measured by question 4, stating ‘I find Physics interesting’, question 6 which stated that ‘it is possible to explain physics ideas without mathematical Equations’ and question 8, stating that ‘Currently, I like Physics very much’.

However, on the relevance of physics to pupils’ everyday life, the findings indicated that both groups, experimental and control group, had comparably the same attitude scores, before and after instruction. Finally, the study reveals that the contextualized teaching materials incorporating IK and pupils’ environment had a considerable effect on pupils’ attitudes towards physics as measured by gains in questions 3, 4, 6 and 8 already discussed in the previous sections.
References


The SECURE Project Research on Science Curricula and Teachers’ and Learners’ Opinions on Science Education

Dagmara Sokolowska, Institute of Physics, Jagiellonian University, Krakow, Poland
Wim Peeters, Dienst Katholiek Onderwijs vzw, Antwerpen, Belgium
Job De Meyere, Thomas More Kempen, Geel Belgium
Leopold Mathelitsch, Universität Graz, Austria
Costas Constantinou, University of Cyprus, Nicosia, Cyprus
Gesche Pospiech, Technische Universität Dresden, Germany
Marisa Michelini, Università degli Studi di Udine, Italy
Elvira Folmer, Wout Ottevanger, Marja van Graft and Wilmad Kuiper, Studiecentrum Leerplan Ontwikkeling (SLO), Enschede, the Netherlands
Barbara Rovšek, Univerza v Ljubljani, Slovenia
Göran Nordström, University of Gävle, Sweden
Gren Ireson, Nottingham Trent University, the United Kingdom

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Correspondence concerning this article should be addressed to Dagmara Sokolowska, Institute of Physics, Jagiellonian University, Reymonta 4, 30-059, Krakow, Poland. E-mail: ufdsokol@cyf-kr.edu.pl

Abstract

The SECURE project has been founded under the 7th Framework Programme to make a significant contribution to the European knowledge-based society by providing relevant research data and translate them into recommendations that contribute to the public debates on mathematics, science and technology (MST) curricula and their objectives in view of balancing the needs between training future scientists and broader societal needs. A rigorous research program conducted by the SECURE consortium scrutinizes and compares current MST curricula for pupils aged 5, 8, 11 and 13 in ten member states, as they are intended by the authorities (legal documents), implemented by the teachers and perceived by the learners. The research at all three levels is designed in accordance to the curricular spider web (van den Akker, 2003). The instruments used to this end consist of a transnational comparative screening instrument for MST curricula, as well as teacher and learner questionnaires and interview protocols. Research in altogether 150 classes of each age has been done by the middle of the project lifetime. Currently the elaboration of summaries of national curricula documents takes place and the analysis of the school collection data at the national level is carried on. The results will be delivered in the last six months of the project lifetime.

Keywords: MST education, European program, research in science education, curriculum, teacher, learner, perception, curriculum spider web, questionnaire, interview, recommendations

Introduction

In its latest policy initiatives and outputs in education and training the European Union restated the importance of science literacy and numeracy as fundamental elements of key competences (European Commission 2010; European Council, 2009, 2010). It was recognized that more investment should be undertaken to increase the number of graduates in science, technology, engineering and mathematics (STEM) so as to create the right conditions to deploy key enabling technologies, essential in the R&D and innovation strategies of industry and services. (European Commission, 2010)

Rationale

SECURE is founded as a collaborative project under FP7 to provide research results of current mathematics, science and technology (MST) curricula across Europe. The overall aim of the SECURE project is to make a significant contribution to the European knowledge-based society by providing relevant research
data that prompt public debates on this issues. Based on good practices and other research results SECURE will formulate a set of recommendations for policy makers and other stakeholders on how MST curricula and their delivery can be enhanced. These improvements would need to focus on encouraging and preparing children from an early age on for future careers in MST. At the same time curricula should make MST more accessible and enjoyable for all children so that they will always keep a vivid interest in mathematics, science and technology, understanding the importance of their societal role.

**Theoretical Framework**

Different meanings of “curriculum” can be found in different contexts of educational research (Taba, 1962; Beauchamp, 1982; Jackson, 1992; Pinar, Reynolds, Slattery & Taubam, 1995; Walker, 2003). Processes of curriculum development are focused on the improvement and innovation of education. Since the process of curricular development usually takes place in several years and, as van den Akker and Kuiper (2007) have shown, is usually characterized by multi component cyclical structures, the ongoing curriculum research may be used to ameliorate incessantly the quality of the development process and the curriculum itself.

To get a complete overview of the curriculum, its analysis should be done at five different levels with respect to the curriculum users (van den Akker, 2003): Supra (international), Macro (national), (Meso (school, institute), Micro (classroom, teacher), Nano (pupil, individual). Another perspective refers to the typology of curriculum representations, built on the work by Goodlad (1979) which is especially useful in the analysis of the processes and the outcomes of curricula. Six different representations of a curriculum are shown in Table 1.

In 2003, van den Akker proposed curriculum representation on a spider web (Figure 1) with Rationale located in the center and nine other components (Aim and Objectives, Content, Learning activities, Teacher role, Materials and Resources, Grouping, Location, Time, Assessment) placed around it, becoming the nine threads of the spider web, connected at five curriculum levels.

**Objectives**

The specific objective of the SECURE project is to provide relevant and rigorous research data and translate them into recommendations that contribute to the debate among policy makers on science curricula and their objectives: balancing the needs between training future scientists and broader societal needs.

The cores of the project are: the analysis, the comparison between the aims and the content of the current MST curricula in the member states; identification of shared grounds among existing MST curricula; identification of good practice in the member states; establishing how curricula are put into practice by MST teachers and how current curricula affect learners’ competences, motivation and perception of the relevance of mathematics, science and technology.

**Method**

A total of 11 partners in 10 EU countries (Figure 2), of which 7 universities and 2 pedagogical institutes are involved in the project: Thomas More Kempen (Belgium), Dienst Katholiek Onderwijs vzw (Belgium), Universität Graz (Austria), University of Cyprus (Cyprus), Technische Universität Dresden (Germany), Università degli Studi di Udine (Italy), Studiecentrum Leerplan Ontwikkeling (the Netherlands), Uniwersytet Jagiellonski (Poland), Univerza v Ljubljani (Slovenia), University of Gävle (Sweden), Nottingham Trent University (the UK).

The SECURE research is focused on 5, 8, 11 and 13 year old learners, their science curriculum and their teachers. The choice of these ages was done to investigate in a comparable way among the involved countries the bridges and the gaps that exist in curricula, on one hand - between kindergarten and primary school and, on the other hand - between primary and middle schools.

To ensure a profound view on the MST-curricula at the different levels, the research focuses on:

1. The formal intended MST-curriculum by comparing written MST curricula in the 10 participating EU countries. It was decided to focus on mathematics, technology (technics), and (natural) sciences (restricted to biology, chemistry and physics, physical geography).
2. The implemented MST-curriculum which takes into account the perceptions of teachers who put the curricula into practice in the day-to-day class activities.

3. The attained experiential curriculum which focuses on the learning experiences of the pupils, the final and most important recipients of the MST-curriculum.

Implementation of the Research in Schools

Data collection in schools took place in two phases: a pilot study, conducted only in four member countries (Germany, Italy, the Netherlands and the United Kingdom) and, then, the systematic, core studies. The pilot study involved a small number of classes and was performed to test and evaluate the first version of the school data collection instruments. After piloting, the instruments were redesigned and in all ten member countries the systematic collection of data in schools has been performed in 15 classes of each age group of learners. On the whole approximately 600 classes, 1000 teachers of mathematics, science and technology, and 10000 learners have been involved in the study.

Research Instruments

The research framework was constructed upon the curriculum spider web (van den Akker, 2003). The research instruments consist of curriculum screening instrument (CSI), and of the school data collection instruments: teacher questionnaires, learner questionnaires (limited to 8, 11 and 13 year olds) and interview protocols for all age groups of pupils and their teachers.

Curriculum screening instrument

The curriculum screening instrument consists of two formats:
- the “format1” level, which provides, in a descriptive way, all information on the documents themselves;
- the “format 2” level, giving in depth insight into the curricula documents and answering the questions about their content, relating to all 10 fields, as the spider web indicates.

School data collection instruments

To get information on the perceptions of people involved in these curricula, draft questionnaires for all ages of learners (except 5 year olds) and the teachers are developed, using the curriculum documents mentioned above. The questionnaires are grounded on existing scientific literature on science education and science curriculum reform. (e.g. Atkin & Black, 2003; Black & Atkin, 1996; van den Akker, 1998). Existing instruments from previous relevant studies such as Alting (2003), Bennett, Gräsel, Parchmann and Waddington (2005), van Driel, Bulte and Verloop (2008), van Langen (2005) – and Schreiner and Sjäberg, (2004), TIMSS (1995, 1999, 2003, 2007), and PISA (2000, 2003, 2006, 2009) have all been used as a starting point for the development.

Other useful sources for instrument development and use could be research instruments developed/applied by SECURE partners, including those instruments currently being used as part of a comprehensive evaluation study on new context-based science curricula in Dutch Senior Secondary school (Kuiper, Folmer, Ottevanger & Bruning, 2009, 2010).

All questionnaires were piloted and very extensively discussed, question by question by members of the SECURE design and analysis group. During these discussions very different opinions and perceptions on education and educational systems occurred. Nevertheless the group agreed on the set of questions put forward. The spider web framework upon which everybody agreed was very helpful for reaching such agreement.

Apart from questionnaires, SECURE also decided to gain additional information on teachers’ and learners’ perceptions by organizing interviews. The guidelines for these interviews were provided, again, discussed in depth by the research and analysis team. All partners report on the results of the interviews according to a given format. Key ideas of this format are: (1) additional information must be gathered, (2) the information should be in line with the questionnaires, following the spider web framework, (3) the report
should contain a summary of all interviews of the same kind (horizontally), (4) the report should mention relevant and clear quotes of the people being interviewed as examples of how ideas are expressed.

Data and findings

Curriculum Screening Research

The most common MST curriculum documents of all disciplines in a country (Macro level or sub-macro level) have been screened according to the designed curriculum screening instrument, covering all 10 fields of the curriculum spider web. The documents used have different origins but need to be official or at least authorized.

With “format 2” each member country provided an extended and descriptive summary of all relevant MST curricula of about 40-50 pages. All of them have basically the same content.

However, after the first attempt of the cross-country analysis it was revealed that the results are less consistent than previously expected, thus an additional set of specific questions has been prepared by partners and the second, more profound round of curriculum screening is taking place.

Data Collection in Schools

Questionnaires

After intensive discussions the questionnaires were adapted by the design and analysis work group of SECURE and made slightly flexible, looking for a suitable equilibrium between reaching the goals of getting information on teachers’ and learners’ perceptions in their given educational system and relevance for the research itself. This was possible since the results of the questionnaires did not need to be analyzed in a comparative way, but would be used to generate a country-specific information on the perceptions of teachers and experiences of learners of the visited schools in view of the written curricula (triangulation analysis). However the questionnaires having a solid common ground still make it possible to extract examples of good practice transferable to other countries.

The teacher questionnaire was split in two parts: one for the mathematics teacher (176 questions), and one for the technology/science(s) teachers (more than 180 questions). It was asked to fill out only questions relating to the discipline given in the same class that was questioned (if disciplines are integrated or if teachers teach several disciplines the advice was that all relevant questions need to be filled out). The bundle contains 23 pages and on average it took about 1 hour to fill it in.

The questionnaires for the 13 year olds were rather complex because in most project partner countries learners get several disciplines given by several different teachers. The questionnaire contains about 234 questions and on it took about 1 hour to complete the questionnaire. The 11 year olds got almost the same questionnaire. However, in countries where integrated science is taught for that age, the number of questions could be slightly reduced. It resulted in 13 pages of questions.

The 8 years old got a reduced questionnaire, not covering three of the 10 fields of the spider diagram, i.e.: the rationale (vision, mission), aims & objectives of curricula, the role of the teacher. It was judged that for those fields it would be too hard for learners of that age to give adequate answers to questions. 111 questions are posed on 5 pages.

The 5 years old learners is a different story. After some preliminary piloting of very simple questionnaires with a limited group of 5 years old, it was recognized that it would be extremely difficult to get relevant answers from them. Hence no questionnaire for 5 years old has been implemented within SECURE.

Interviews

It was decided to use the interview research tool in 6 out of 15 classes of each age per country and to interview in those classes all teachers of all disciplines covered by the research. Such an interview took typically approx. 45 minutes. In the same 6 classes of age 8, 11, 13, a set of 4 learners (2 girls and 2 boys) randomly chosen were also subject to an interview. These lasted about 35-40 minutes each. Since no other means were left, the only way of getting information from 5 year olds was by interviewing them, like
the other classes, 2 girls and 2 boys, but of all 15 classes involved. The interview was set up to cover only two fields of the spider web. These also took usually little more than 30 minutes.

**Discussion and Conclusions**

Given the preliminary analysis of the curricula of 10 countries on the ten spider web components, a transnational comparative study is taking place. Data of questionnaires are brought together and are now being analyzed in depth. A large part of the students and the majority of the teachers expressed thanks for the quality of the questionnaires and the opportunity given to them to reflect on some curricular aspects in a guided way. Teachers remarked also their interest in dissemination of the results and were curious to compare the situation of their own classes with the other. An analysis method on the interviews is adapted and is carried out now.

The final research report is planned to be prepared in the following months. Almost five months before the end of the project, a meeting of the external expert group will take place to study the results, to give feedback on study conclusions and forthcoming recommendations and to give an opinion of the relevance of the project findings from the perspective of other countries, mostly from the EU.

Other European projects will benefit from the SECURE outcomes, adapting their strategy and the implementation methods of the research done. The dissemination of the results is foreseen from the beginning and the length of the 2013 aim at returning the results to the schools that cooperated, inform local and national authorities on the outcomes and inform the European educational MST community as well.

Documentation of data collected, its analysis and the production of reports on the aspects of the curricular spider web for math, science and technology will be disseminated. To reach this goal, seminars and scientific happenings will be organized inside the involved school, in the partners’ organizations and through mass media.

**Acknowledgement**

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**References**


Figure 1. Curriculum spider web

Figure 2. SECURE member states

Table 1. Curriculum representations

<table>
<thead>
<tr>
<th>Intended</th>
<th>Ideal</th>
<th>Vision (rationale or basic philosophy underlying a curriculum)</th>
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<tbody>
<tr>
<td>Formal/written</td>
<td>Intentions as specified in curriculum documents and/or materials</td>
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<table>
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<tr>
<th>Implemented</th>
<th>Perceived</th>
<th>Curriculum as interpreted by its users (especially teachers)</th>
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<tbody>
<tr>
<td>Operational</td>
<td>Actual process of teaching and learning (also: curriculum in action)</td>
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<tr>
<th>Attained</th>
<th>Experimental</th>
<th>Learning experiences as perceived by learners</th>
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<tr>
<td>Learned</td>
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<td>Resulting learning outcomes of learners</td>
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An Analysis of the Potentialities of a Scientific Literature Book on Physics Teaching

Cristina Leite, Instituto de Física - Universidade de São Paulo, Brasil
Fernanda Marchi, Programa de Pós-graduação em Ensino de Ciências – Universidade de São Paulo, Brasil

Abstract

Considering the peculiarities related to the incentive the act of reading to Brazilian students, two theories related to teaching and encouraging this habit in Brazilian schools are raised by Silva (1998). One refers to the responsibility of all teachers to develop this practice in their disciplines. The other one says that “the creative imagination and fantasy are not exclusively to be developed on literature classes.” (p.122). The Astronomy themes can make this activity more pleasurable in science teaching, such that, through reading, a student can understand the contents of this area and become a proficient reader. In this work we selected the book entitled “George and the Secret to the Universe”, written by a popular science communicator, Stephen Hawking, and his daughter, Lucy Hawking, for a possible use in the classroom. The analyze is based on Ribeiro’s work (2007), which identifies the characteristics of scientific dissemination texts, such as the context and relevance of the topics covered on them, their simplification, the image of science and scientists and the sensationalism presented on them. The potentialities of this book, when teaching and learning objectives are intended to be achieved, are also analyzed: the students’ introduction into the world of reading and their formation as critical readers. It seems that the selected book has the black holes as the main theme, as well as the stellar evolution and other topics related to the origin of the universe. The proposed analysis gives some points of view that can be considered when the reading ability is intended to be stimulated in classroom. So, in this work, it’s proposed that Astronomy and the construction of scientific knowledge can stimulate the curiosity, imagination and fantasy, which are assigned as reading purposes that can be well addressed through topics related to this scientific area.

Introduction

Two important theories related to the practice of reading in Brazilian schools and considering the low number of books that are read by the Brazilian population in general, are raised by Silva (1998). One of them refers to the responsibility of all teachers by the formation of readers and the development of the practice of reading in their disciplines, independently of what subject they teach. The other one says that the creative imagination and the fantasy should not be developed only in literature classes, but it should and can be developed in all disciplines in school.

When we think about the practice of reading in science classes of elementary school, maybe it can remind us of the textbooks that are commonly used in teaching this subject. More broadly, we could think about other resources in school context, such as science magazines, newspapers, reports of not specialized journals in science, or science fiction books. Furthermore, this could encourage the practice of reading or introducing the students to think about provocative themes, which could instigate the curiosity and interest of students in reading. In this sense, themes of astronomy can make this activity more enjoyable in classroom, so that, through this type of reading, a student can understand the contents of Astronomy and this may contribute to the stimulation of this habit, extending beyond school.

Themes related to physics and astronomy are recurring in popular science books written by scientists themselves, which may allow a greater dialogue between the production of knowledge and its dissemination. In order to better understand some of these books and its possibilities of uses in class, in this work, the one called “George’s Secret Key to the Universe”, written by one of the most popular science divulgators nowadays, Stephen Hawking, in partnership with his daughter, Lucy Hawking, is analyzed.

This book is aimed to be read by children and teenagers, and it addresses matters related to astronomy, treating these topics in the curriculum school as others who are part of the curiosity and imagination of the students. These are discussed in a simplified manner through a literary narrative, taking advantage of the actions that occur in the story for the insertion of the concepts science through the dialogues between the characters, which focus on themes as the Solar System, the Comets, the Moon and even the latest ideas developed about Black Holes.
The inclusion of a book of this nature in the classroom can help the learning and teaching of scientific contents, given the characteristics of the text and its language that simplifies the approach of the knowledge of science, in opposition to textbooks, which language is predominantly formal (GIRALDELLI & ALMEIDA, 2008). But when one thinks of conducting reading activities in the classroom, it should be borne in mind that the pedagogical act of teacher requires much more than the simple insertion of a book is not didactic in class (SILVA, 1998, p.7).

**Methodology of Research**

The analysis of the book is based on the work by Ribeiro (2007), developed from Paulo Freire’s educational approach. It brings many important elements for the analysis of scientific divulgation texts from two perspectives: the inherent characteristics to the texts and the perspective of the formation of readers and critical readers. The following characteristics of the text were analyzed as:

i. **Simplifying/reducing the complexity of scientific knowledge**: the use of some resources that simplify the scientific language in order to achieve a specific target audience;

ii. **Image of science**: this category seeks to identify how science and scientific activity are presented in scientific dissemination texts, that many times are associated with great discoveries, the technical advancement, the improvement of life and the human search for truth, the existence of a unique scientific method that is infallible (RIBEIRO, p. 44) and the construction of a stereotype of a scientist;

iii. **Sensationalism**: it is analyzed in the text if the science is treated in an exaggerated way and transforming the scientific concepts and theories into events with strong emotional appeal.

The educational potentialities of the selected material are analyzed under the following aspects:

i. **Contextualization and atualization**: the texts may help in the renewal of content and in the discussion of provocative themes present in the media;

ii. **World of reading/reading the world**: the text can be considered a tool that enables the development of abilities and skills of readers, leading them to its discovery, an activity that contribute to science and also lead the student to rediscover the world.

iii. **The training of a critical spirit**: seeking to stimulate a reflexive attitude through the reading and stimulation of the contact with a variety of materials and to the reality for the process of production of scientific knowledge and its applications.

**The analysis**

The book tells the story of George, a very curious boy and that is interested about science, but whose parents do not like the modern inventions, and seeks to lead a life away from technology and the supposed evils provided by science. By an accident, due to the leakage of his pet, a pig, for the neighboring house, he met Annie, a girl near his age, and Eric, a scientist and owner of an “overpowering” and “superintelligent” computer called Cosmos, which is able to open windows and doors to outer space and show all the wonders of that can lead the characters to travel throughout the incredible Solar Solar. Dr. Reeper, the villain of the story, is a Professor and an enemy of Eric. They studied physics at university Reeper became interested in the pursuit of knowledge that was not related to the beneficial to humankind, trying at all costs to get rid of his former teammate and steal his research, the “Cosmos” computer.

Themes such as Black Holes or the Stellar Evolution can stimulate the curiosity of students, once they are “present in the media, just part of day-to-day lives of students” (RIBEIRO, 2007, p. 112), so that the reading of the book discussed in this research can promote the contextualization and update of content of the physics curriculum. In this book the theme “Black Holes” id presented in the spotlight of the story, once it is being exclusively addressed in the twenty-sixth chapter of the work, becoming a book inside the main one and that can be read independently of the main narrative.

The narrative is mainly developed with the instigation of the development of scientific knowledge and the scientific concepts are largely covered and explained through dialogues, stimulated by Georges’ curiosity
and the explanations given by Eric, the scientist who apparently represents the personality of Stephen Hawking in the text.

The story seems to be written with the intention to stimulate the imagination and fantasy of the readers, since Eric can open doors through his computer and show “some of the wonders of the universe” (HAWKING & HAWKING, 2007, p. 45). When Eric opens the window to the universe, he tries to answer all of the George’s questions, what also reinforces the stereotype of the scientists, who are all able and have all the knowledge to answer questions about science. Furthermore, there are many other moments of fantasy that are encouraged by the main characters; for example, when George and Annie travel through the space on a comet. Annie, Eric’s daughter, is a girl that explains all her knowledge that was learned with his father when George asks her anything about science. This is a way that the authors build the scientific concepts and presented many phenomena to their readers. Through the dialogues, the authors try to explain the knowledge in a simplified manner, what is classified as simplification - reducing the complex, bringing these scientific concepts in a gradual and informal way, using also other some resources as language definitions, which make the scientific concepts and theories closer to the reader.

On the birth the stars and the definition of nuclear fusion, see how the subject is addressed through dialogue between George and Eric:

“- Wow! - Exclaimed George. - Is it the Sun?
- It could be - Eric replied. - This is how stars are born, and the Sun is a star. When a huge amount of gas and dust combines and cringes becoming dense and hot, as you saw, the center of the ball particles are compressed as they begin to fuse, releasing enormous amounts of energy. This is called a nuclear reaction fusion. It is so powerful that early expels layers outside of the ball and the rest becomes a star.” (p. 56, emphasis added).

From this analysis it was possible to identify the inherent characteristics in the texts of disclosure, i.e., the use of some resources, such as analogies, comparisons and metaphors that simplify the language presented in the texts, and also the use of illustrations as a complement to the scientific concepts, as the examples that follows:

“The edge of a black hole is called the “horizon”. It is like the edge of a waterfall. If you are above the edge, you can get away if you paddle fast enough, but once you pass the edge, you are doomed.” (p. 238, emphasis added)

“As more things fall into a black hole, it gets bigger and the horizon moves farther out. Its like feeding a pig. The more you feed it, the larger it gets.” (p. 238, emphasis added)

And also Eric describes a black hole as this:

“The answer is: you can’t see a black hole because it does not let light come out of it. It’s like looking for a black cat in a dark basement. But one can detect a black hole by the way its gravity attracts other objects. When we see stars orbiting around something invisible, something we know this can only be a black hole. “(p. 242, emphasis added)

As the analysis categories listed above, the analyzed text seeks to bring its readers the discovery and rediscovery of the world around them, to extend their experiences and knowledge to other contexts beyond their immediate world (SILVA, 2005) through science, and a new way of perceiving the “world.” In the example below, Eric talks about his work as a scientist and brings the reader to your questions:

“There are many different types of natural science, and they have very different uses. The guy I work revolves around the “how” and “why.” How it all began: the universe, the solar system, our planet, life on Earth? What existed before this start? Where did all this? And how it all works? And why? This is physical, George, exciting, brilliant and fascinating physics.” (p.32, emphasis added)

The image of scientists is built around the stereotype of forgotten people, messy and intelligent ones:

“A tall man with messy dark hair, and thick, heavy-framed glasses, set at a ckhrooked angle on his nose, walked into the kitchen.” (p. 25)
“He started to clean up some of the mess the scientists had made. They seemed to have left behind an extraordinary number of things: jackets, hats, sweaters - and even a shoe.” (p. 200)

The sensationalism becomes evident with the overvaluation of science, shown as something fantastic and wonderful in order to capture the reader’s attention to the reading of the scientific narrative.

Under the eyes of sensationalism and the image of science, we find that the book considers a stereotypical image of science, scientists and the scientific activity that are widely reproduced in the text:

“A tall man with unkempt black hair and thick-rimmed glasses on his nose tilted thick, into the kitchen.” (p. 25)

“- You have to try harder if you want to be a scientist. Think! What could it be? The answer is very easy.” (p. 166)

“- And began to clean up the mess left by the scientists, who had forgotten an extraordinary number of objects: jackets, hats, jackets ... even a shoe.” (p. 200)

“The carpet was covered in footprints left by scientists because none remembered to clean his shoes on the mat of the door.” (p. 202)

One can see that the image of scientists presented is the subject of forgotten, carefree and also intelligent. Beyond these examples, there are illustrations that reproduce this image showing stacks and stacks of books lying around the house of Eric, and many “squiggles” (or equations) on blackboards and impossible to be understood by non-specialists.

As for scientific activity, we have an image that can lead the reader to believe in the existence of a (or the) scientific method, a single, infallible, which occurs through the testing of hypotheses through repeated experimentation and observation, besides the overvaluation science throughout the text:

“Science is a vague word. It means explaining the world around us using our senses, our intelligence and our capacity of observation.” (p. 32)

“- The science also deals with the acquisition of knowledge through experience.” (p. 38)

- Is - Eric agreed. - Science is a wonderful and fascinating subject that helps us understand the world around us and all its wonders.” (p. 31)

“(…) This is a physical, George, exciting, brilliant and fascinating physics.

- But it’s really interesting! - Exclaimed George. “

- In outer space there are things you ever imagined! - Continued Eric. - Extraordinary things, fascinating, huge and amazing, but dangerous. Too dangerous! And I would tell you about them (…)” (p. 136)

Similarly we find that the overvaluation of science, we see the concern of the authors demystify it, unlinking your image to magic, which can also confuse readers about the image of science. After Eric perform a simple experiment, and George dazzles question:

“- Is it magic? - George yelled, suddenly excited (…) - Are you a magician?

- It’s Science, George - Eric explained, with a twinkle in her eye. - Science.

- My God, this is fantastic! - George whispered. “ (p. 31)

In these examples, it appears that while it seeks to show that the course of history through science and knowledge the individual can relate differently with the world around them, science is treated overvalued, with in order to capture the attention of your readers to the scientific explanations that follow in the text.

Regarding the contextualization and actualization, the book covers topics such as black holes, stellar evolution, exoplanets, the reclassification of Pluto, among others, which are present in the media and is part of everyday life of students. In terms of actualization, it is highlighted on the cover of the book that in the narrative it is discussed the latest ideas about black holes.
Considering the stimulation of fantasy and imagination of readers, the most important element of the story which stimulates them is the computer called “Cosmos,” which can open doors to the main characters to travel throughout the universe.

The book offers a multiplicity of readings, whether it is related to texts or images. The book consists of a literary narrative in which the events in the story are used to illustrate concepts of physics for kids.

Some boxes appear throughout the story, being a resource that can be used by the reader to deepen the concepts covered in the narrative. In addition, there are other visuals, called “cosmo’s pictures files,” which features real and color images of various objects like the moon, the sun, nebulae, among others.

The stimulation of the critical vision to reality and to the production process of scientific knowledge throughout the reading of this material is only possible to be developed by the one who mediates its reading, once it was written to introduce physics for kids and not to clarify those ideas to the reader. As it was identified through the analysis, the image of scientists is built around a stereotypical image and in order to capture the reader’s attention, the science is overvalued through the whole story.

n these examples, it appears that while it seeks to show that the course of history through science and knowledge the individual can relate differently with the world around them, science is treated overvalued, with in order to capture the attention of your readers to the scientific explanations that follow in the text. While it

Other elements present in the text that can entertain the reader and stimulate this activity (RIBEIRO, 2007, p. 117) are the visuals in parts of the text. They are called “archive images of the Cosmos,” brings images of the Moon, the Sun, nebulae, the Milky Way, the Earth and other planets, the setting of the sun on Mars, among others. Besides the images, it also pits explaining that to the reader more curious, play the role of deepening the concepts or ideas discussed throughout the narrative and that may hinder the development of reading more technical information is inserted in the body of the story.

Considerations

Given the space constraints and extension of the analyzed text, the depth of the subject and the scientific understanding of the issue involved in this proposed work, as the black holes and the popular science books, although the approach of seeking readers through a language that does not use math, should not be seen as texts to be read “is exhausted in the text itself” (PIETRI, 2007, p. 78). As part of the training process of the student their spur and guide to search for bibliographic sources such as dictionaries of science, physics and astronomy and also the multiplicity of visual resources that are available nowadays can contribute to the formation of the readers inside and outside the school context.

Taking into account the scientific cosmological and astronomical themes, when working with a text about these themes that are proposed here and considering its potentialities to stimulate the understanding of the universe in which those subjects are included, as well as stimulating further development of scientific concepts covered in text can be thought that such material conducive to students/subject readers understanding of the scientific context in which they are situated, but also development of subjects proficient readers that, in addition to the texts that are proposed are formed as viewers in search of other bibliographic sources, regardless of the multiplicity of ways in which these texts are now available.

Many of the elements identified in the analysis above are not revealed immediately for the readers being it needed a prior knowledge on the part of the one who proposes to mediate their readings in the classroom. The stimulation of the critical vision to reality and to the production process of scientific knowledge through the reading of this material is only possible to be developed by the one who mediates its reading, once it was not produced to clarify this ideas to the reader, but to explain physics for kids. Besides introducing the reader to several themes that are not necessarily part of the physics classes, some care must be taken to introduce these materials in their classes. As we have seen the book presents the image of science and overrated stereotypical image of scientists, issues to be discussed by those who wish to take the book as reading material for teaching physics. But despite these limitations, the book indicates a potential use as a means to educate scientifically, contributing to the important task of taking students to
the world of imagination and creativity by reading a scientific adventure filled with contemporary content of Physics and Astronomy.

References


Hands-on Supporting Pupils in Understanding the Process of Vision

Claudia Haagen-Schuetzenhoefer, University of Vienna, AECC Physics
Benjamin Wallner, University of Vienna

Abstract

The objective of this contribution was to present a simple hands-on experiment that supports students in understanding the process of vision within the field of geometrical optics. Research has shown that pupils, especially in elementary instruction of geometrical optics, find it difficult to understand that visual perception can only occur if light - either emitted by primary light sources or scattered by secondary light sources - enters the observer’s eyes. This explains why a vast majority of pupils tend to believe that they can see in the dark. Or, to put it the other way round, as pupils have experienced throughout their life time that they can see in conditions they conceptualize as “darkness”, they cannot establish a relation between light entering their eyes and vision. In order to trigger learning processes we developed a hands-on we called “Vision Tube” and tried it out in a year 4 class. The teaching-learning sequence we used was based on the POE (Predict – Observe – Explain) structure. The analyses of this interventions show that the “Vision Tube” supported students in understanding the process of vision. Its use in class turned out to be simple and effective since the experience of “real darkness” can be achieved quite easily contrary to settings where the classroom is darkened.

1. Introduction

Pupils’ ideas of vision have been investigated thoroughly over the last decades. Research has repeatedly shown that pupils bring several categories of alternative conceptions concerning the process of vision to their physics lessons (Duit, 2009).

Guesne (Guesne, 1985) has classified the most frequently held conceptions concerning vision into four main categories:

(1) Pupils holding the “light bath idea” act on the assumption that an object can be seen just if there is light around it. They do not specify any relation between light and the object, however.

(2) Pupils having the “illumination of an object” conception usually identify light as an entity travelling in space that is scattered by the perceived object. Though, they frequently ignore the relation to the observer.

(3) Pupils using the “active eye” model believe in some kind of active mechanism inherent to the human’s eye. They think that an object can be seen when light shines on it and when they actively look at it at the same time.

(4) Finally, a minority of pupils tends to hold what Guesne called “the physicists’model”. It is based on a mechanism that links the object with the observer’s eye, light being a mediator between them.

For our purposes we simplified the complex process of vision following the educational reconstruction as used by de Hosson et. al (de Hosson & Kaminski, 2007). They reconstructed the mechanism of vision for the age group of 10 to 15 year old children in a two part-model, consisting of a physical and a psycho-physiological part. Part one focuses on the processes taking place in front of the retina, whereas, part two of the model describes processes between the retina and the cortex. For our intervention we concentrated on the first part of the model, the physical one, which summarizes that we can perceive objects when they send off light into our eyes.
Conventional instruction is usually not very successful in transforming these everyday conceptions into scientifically adequate concepts about vision (Andersson & Kärrqvist, 1983; Fetherstonhaugh, Happs, & Treagust, 1987; Langley, Ronen, & Eylon, 1997; Heywood, 2005; Chu, Treagust, & Chandrasegaran, 2009). Several reasons can be named for the persistence of alternative conceptions about vision: One reason seems to be rooted in traditional instruction of geometrical optics itself. It looks that the concept of vision is frequently treated in a superficial way. We found hints supporting this assumption when analysing Austrian schoolbooks as well as in a survey asking Austrian high school teachers’ (N=22) about the most important key concepts they base their optics lessons on (Haagen-Schützenhöfer & Hopf, 2012).

Generally, school books can be seen as a good predictor for the key ideas teachers base their lessons on. Many Austrian text-books do not pay attention to the process of vision or just summarize it superficially at the beginning of the chapter on geometrical optics. A similar situation holds true for the idea that objects – whether light sources or not – can give off light under certain circumstances (Selley, 1996). The concept that we can only see objects because they scatter light is frequently neglected.

Similar results were achieved when asking teachers for the importance of the concepts of vision and scattering of light in their optics lessons. As our research shows (Haagen-Schützenhöfer & Hopf, 2012), teachers frequently regard the process of vision as a trivial one, being self-explanatory and thus it is not necessary to pay special attention to it.

Another reason why pupils misinterpret the process of vision is that they have only rarely the experience of “real darkness”, so to speak the experience of total absence of light. What they conceptualize as “darkness” is in fact the absence of a direct light source but the presence of scattered light. So pupils deduce from their everyday experiences that they can see even when it’s “dark” (Jung, 1982; La Rosa, Mayer, Patrizi, & Vicentini-Missoni, 1984). For pupils this frequently implies that light entering the eye is not a necessary condition for vision.

One idea to promote the understanding of vision was to create a learning environment that makes pupils familiar with the experience of “real darkness”. Usually it is quite tricky to create “real darkness” in class rooms. Additionally, it is not always easy to handle a class of teenagers in total darkness. Considering this, our objective was to develop a hands-on experiment that can be easily built and is simple to handle in class. The purpose of the evaluation conducted was to analyse learning effects triggered by implementing the “Vision Tube”. Our two main research questions were:

1. Does the use of the “Vision Tube” promote pupils’ understanding of the process of vision?
2. Does the use of the “Vision Tube” promote pupils’ understanding of selective re-emission of secondary sources on a qualitative basis?
2. Methods

Participants & Setting

The teaching-learning sequence designed for implementing the “Vision Tube” was aimed at elementary science education, so to say at pupils who have never encountered this issue in the course of formal instruction before. We tried the “Vision Tube” for the first time with pupils in year 4 of primary school, who were at the beginner’s stage of science education. The class (N=14) consisted of 8 girls and 6 boys who were between nine and ten years. The pupils were instructed in German. More than half of them were not native speakers of German but had a migration background.

As setting for our teaching-learning sequence we chose the pupils’ familiar surroundings of their classroom. The teaching-learning sequence on introductory optics, which was carried out by the co-author, lasted in total for two succeeding 50-minutes lessons. The part focusing on the concept of vision lasted for about 50 minutes. The class teacher was present during this intervention. The full intervention was videotaped. Additionally, the pupils were given two test items (Guesne, 1985) before and after the intervention.

The “Vision Tube”

The main aim for our intervention was to develop a hands-on experiment that can convey the experience of “real darkness” to each pupil. We made several attempts and tried different constructions and finally came up with a quite simple to produce and to use tool we called “Vision Tube”. It consists of a plastic water pipe intersected by a red and with striped stick. One end of the plastic water pipe is closed firmly. Above the intersected striped stick, there is a small hole in the plastic tube that functions as light inlet.

Our hypotheses was that the “Vision Tube” is able to promote learning due to the different quality of sensations an observer can gain of the intersected stick, depending on the quality of light incidence into the “Vision Tube” (see Fig. 3). When the small hole of the “Vision Tube”, which functions as light inlet, is put directly below a lamp, an observer looking through the open end of the tube can see the intersected stick and its red and white stripes. When the “Vision Tube” is rotated (Fig. 3b) and only stray light can enter the small hole then one can perceive the stripes of the intersected stick only as different shades of grey. As soon as the hole is firmly covered, e.g. by pressing a finger against it, no light can enter the “Vision Tube”. As a consequence, no light is scattered by the intersected stick and the stick cannot be seen anymore.

Our hypothesis was that these experiments can convey the idea that light coming from an object and entering the observer’s eye is a prerequisite for seeing this object. In addition, we thought that the different appearance of the white and the read strips under varying light conditions may contribute to the understanding of absorption and selective re-emission processes of light (scattering) on a qualitative basis.
The intervention with the “Vision Tube”

The teaching-learning sequence on vision was designed following principles for constructivist learning environments. As method we used the POE (Predict – Observe – Explain) structure (White & Gunstone, 1992): In the first step of this approach pupils are asked for their predictions (P for Prediction) in a certain situation of an experiment. In the second step the experiment is shown or carried out by the pupils themselves. The pupils have to observe carefully and verbalize their observations (O for observation). In the last step pupils are asked to amend or add to their explanation given in the first step (E for explanation). Finally, pupils’ ideas and cognitive conflicts are discussed in class.

For our teaching-learning sequence on vision we used two successive POE cycles. The first one was to recall the everyday experience that objects can be seen in a “dark” room. This experience was planned to be contrasted by the experience of vision in “real darkness” produced by the “Vision Tube”.

The starting point of the first POE cycle was based on an every-day situation, the perception of a red apple on a white plate in a darkened room. The pupils were given the following task for prediction (P1): Look at the red apple on the white plate at the teacher’s desk. What will happen if we turn off the light and close the shutters? Then the room was darkened by turning off the light and closing the shutters. What the pupils accepted as “dark room” in this phase was, however, a room still filled with some ambient light. The pupils then described their observations (O1) and explained them (E1).

The second POE cycle was centred on the “Vision Tube”. In a first step, the “Vision Tube” had to be introduced to the pupils. This was done by presenting the tube to the pupils without giving it to them. The pupils were asked to name and describe the parts of the “Vision Tube”. This assignment was important for two purposes. On the one hand, we got a picture of how the pupils perceive the “Vision Tube”, e.g. if they see that the red and white striped stick is partly inside and partly outside the plastic pipe. On the other hand, it was essential in respect to the non-native background of most pupils to enable them to name the parts of the “Vision Tube”.

After being familiar with the appearance of the “Vision Tube”, the pupils were asked to make two predictions: When you look through the VISION-tube and rotate it. What will you see? (P2a). When you block the light inlet with your finger. What will you see? (P2b). Afterwards, the pupils got a “Vision Tube” to make their own observations (O2a & O2b) and explain them (E2a & E2b).

Data Sources and Analysis

The evaluation of our teaching-learning sequence was based on two different data sources. On the one hand, the full intervention was video-taped from the front of the classroom having the pupils in the focus. Secondly, the pupils got two test items pre and post to the intervention. Based on the young age of the pupils and their general low ability in German and their non-native language background, we decided to keep the testing short and simple and chose two well tried and tested items from Guesne (Guesne, 1985). Figures 4 and 5 show the English version of the items which we used in a German translation.
Which diagram shows why the observer can see the object?

![Diagram](image1)

**Figure 4.** Item addressing different student conceptions about vision (Guesne, 1985, p. 29)

Which object is lit brighter by the spotlight?

![Diagram](image2)

**Figure 5.** Item addressing the idea of reflection as a mechanism of absorption selective re-emission (Guesne, 1985, p. 21).

A frequency analysis was carried out for the multiple choice pre-post items. Parts of the lesson video, including the two POE cycles, were analysed qualitatively (Mayring, 2010). Student statements during the POE phases were categorized based on Guesne’s (Guesne, 1985) four categories of student conceptions about vision.

### 3. Selected Results

**Pre- and Post-Results collected by Test Items**

The frequency analysis of the two items administered before and after the test shows changes in the response behaviour of the pupils after our teaching-learning sequence with the “Vision Tube”.

Before the intervention, less than half of the pupils (6/14) used “the physicist model” in order to explain the process of vision. Most of the pupils (7/14) referred to the “illumination of an object model” at the pre-stage. The “light bath model” was chosen in only one case (1/14). After the intervention most pupils (8/14) chose “the physicist model”, although there were still a lot of pupils (6/14) who opted for “the illumination of an object model”.

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The item focusing on the idea of selective re-emission shows a clearer picture. Before the intervention, nearly all pupils (12 / 14) opted for answer 1. This result was reversed afterwards. Only one pupil did not change his idea. Most pupils (10 / 14) chose the correct answer after the intervention. Another interesting effect could be seen. One pupil ticked both answers in the questionnaire after the intervention. She added that it was the same illumination in both cases.

![Figure 6. Response frequency to the item on vision before and after the intervention. Correct answers are highlighted in green.](image)

![Figure 7. Response frequency to the item on reflection before and after the intervention. Correct answers are highlighted in green.](image)

**Results from the Analysis of the Lesson Video**

This part of the paper focuses on pupil’s utterances during the two POE cycles.

In the case of a red apple lying on a white plate in a “dark” room, pupils’ most popular predictions were “still see it” and “it will be more greyish”. Ten out of 14 pupils mentioned explicitly that objects can be seen in the dark, four pupils out of 14 did not respond. After the room had been darkened by closing the shutters, there was still ambient light in the class room. All of the pupils accepted this state however as “dark room”. When verbalizing their observation of the red apple on the white plate in the “dark” class room, a typical pupil observation was: “I can still see it, it seems dark grey now”. In the explanation-stage of the first cycle pupils used arguments like: “Bright colours still shine, they send off more light” or “dark colours don’t shine in the dark”. A dependency between light and vision could not be traced in the pupils’ explanations. Nine out of 14 pupils had the idea of some “active mechanism” connected to the eye and vision.

When working with the “Vision Tube” in the second POE cycle, pupils could clearly establish a relationship between the intensity of incident light, the reflective behaviour of the red and white stripes and the process of vision. While sensual impressions prevailed in the observation stage (O2a) “The colours get darker when the hole is opposite to the lamp”, most explanations (E2a) were centred on qualitative judgements concerning the mechanisms of reflection: “Light goes through the hole, it’s reflected”, “less goes into my eyes”.

In the last phase, when the pupils had to block the light inlet with their fingers, their predictions (P2b) were quite in line with their prediction in the first POE cycle (red apple – white plate). After the observation with the “Vision Tube” (O2b), however, pupils described the effect of “total darkness” on their vision the following way: “I see nothing, it’s dark inside”. The line of explanation (E2b) indicates that the majority could clearly relate the lack of light entering the tube to their visual non-perception “No light gets inside”, “no light is there – no light can go into eye”.

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4. Discussion and Conclusion

Our teaching-learning sequence which introduces the “Vision Tube” as a hands-on experiment to promote the understanding of vision and scattering of light was evaluated on two different levels. One the one hand, pre- post items were administered and on the other hand, videos of the intervention were analysed. The analysis of the pre-post items shows a knowledge gain for both addressed concepts.

As far as the concept of vision is concerned two out of 14 pupils changed from the “illumination of an object” model to a scientific adequate model. However, there remained still quite a large group of pupils (6/14) who opted for the “illumination of an object model” after the intervention. When interpreting these results it has to be mentioned, that several pupils expressed verbally their difficulties in understanding the representations used in the vision item. The main problems were caused by the arrows in this item, as the same type of symbol, an arrow, represented two different ideas. In the second answer option, an arrow indicates a beam of light as well as the direction of sight.

The reflection item indicates that the intervention with the “Vision Tube” supports the majority of pupils in understanding the concept of scattering as a mechanism based on selective re-emission. One pupil’s objecting that both objects were illuminated in the same way shows the items’ potential for improvement and also hints at a possible distortion of the conclusions draw from this item.

The analysis of the video made during the intervention served as a second basis for the evaluation of our teaching-learning sequence. The intervention was designed along two POE cycles. In the first cycle the “Vision Tube” was not used, but pupils observed white (plate) and red (apple) objects in the darkened classroom. It is important to mention that the “darkened classroom” was not a really dark one due to stray light still being able to enter. In the prediction-stage of this first part of the intervention most pupils thought that they could see “in the dark”. The first observation phase (O1) also supported this belief since what was conceptualized as “darkness” in O1 was not the total absence of light. There actually existed stray light in the room as it is in general quite difficult to darken a normal classroom totally. The lacking experience of “total darkness” seemed to hinder pupils to establish a relationship between an object scattering light, light entering the eye and the visual sensation caused. So their alternative ideas about vision were backed up by their observations and they did not feel any need to change their primary ideas about vision.

In the second POE cycle, the hands-on experiment with the “Vision Tube” (O2) gave pupils the opportunity to experience the effects of changing light intensity or different “surface colours” on the reflecting behaviour of objects. This seemed to support pupils in developing a relationship between visual sensation and objects reflecting light into their eyes. By the end of the second POE cycle all pupils had accepted a relationship between vision and light entering their eyes. In addition, a connection was drawn between the “surface colour” of an object and how much light this object reflected into their eyes.

In sum it up, the hands-on that we called “Vision Tube” is easy to build. Its use in class turned out to be simple and effective in addressing the concepts of vision and selective absorption and re-emission. The experience of “real darkness” can be achieved quite easily with the “Vision Tube”, contrary to other classroom settings. In general, our teaching-learning sequence with the “Vision Tube” appears to help pupils to gain a better understanding of the process of vision. These predominately encouraging results should stimulate further research, examining the learning effects triggered by the “Vision Tube” within other lesson designs, or addressed to other age-groups of pupils.
References


A Didactic Proposal for Wave Optics Learning

Silvia Bravo, Physics Department, Facultad de Ciencias Exactas y Tecnología, Universidad Nacional de Tucumán, Argentina
Martia Pesa, Physics Department, Facultad de Ciencias Exactas y Tecnología, Universidad Nacional de Tucumán, Argentina

Abstract

A didactic proposal consisting of a sequence of theoretical-experimental group activities designed to introduce university students of the first courses to the fundamental concepts of wave optics is presented in this paper. Each activity aims at discussing some of the concepts that constitute the wave optics model and the limits of validity of such model. The proposal is based on the learning theory held by Vergnaud’s conceptual fields theory, which postulates that concepts, procedures and symbolic representations are connected and linked with each other during the process of knowledge acquisition. The sequence of activities that integrates the proposal is also based on the results of previous research on the causes of students’ difficulties in learning wave optics.

1- Introduction

The conceptual field of wave optics constitutes an area of basic knowledge in the scientific and technological development of physicists and engineers; it is also an area of great complexity and difficult to be learnt.

Teaching experience has shown that some of the students’ difficulties when solving problematic situations related to real experimental systems are similar to the difficulties reported on research works on the subject (Maurines 2010; Colin & Viennot 2002, Ambrose et. al., 1999). The following observations can be mentioned as examples:

- inadequate understanding of the most significant characteristics of geometrical optics models and the wave models and lack of differentiation between them. Students work out problems unreflectively, mixing elements of both models, regardless of their explanation contexts.

- lack of understanding of the physical meaning of the wave function regarding its representation forms: time-independent wave function and space-independent wave function.

- uncertainty in the language used to refer to the different concepts.

- lack of clear criteria to relate graphs, patterns of luminous intensity on screens and specific experimental systems.

In order to systematize these learning difficulties, a research (Bravo & Pesa, 2011) on the representations and reasoning that students put forth when facing problematic situations of wave optics has been carried out in a first stage. Theoretical-experimental activities were used as research instruments to get to know the structural nuclei of their conceptions. The results obtained in this first usage of the activities have permitted us to improve the language and the writing out of statements as well as to carry out the necessary adjustments concerning the instructional sequence, thus reaching a proposal of theoretical-experimental work plausible to be used at the university first courses.

This work introduces a didactic proposal based on the learning approach of Vergnaud’s conceptual fields theory and on the results of previous research on the learning of wave optics.

2- Theoretical framework

The CCT provides a cognitivist framework for the development of complex competencies. It permits to understand and explain both continuities and breaks between knowledges through a holistic view of learning, in which the “know to do” and the “know to say” are related, that is, the operative and predictive forms of knowledge (Vergnaud, 1996). It also allows the analysis of how ideas are organized and interlinked and how concepts and representations are generated in the course of time. This theory
postulates that conceptualization is the objective of cognitive development, thus the importance given to the content of knowledge and its conceptual analysis.

According to Vergnaud (1990), conceptual fields constitute large collections of situations and problems whose analysis and treatment require several types of concepts, procedures and symbolic representations which are interlinked and probably intermingled during the process of knowledge acquisition.

A concept cannot be reduced to its definition: it is through situations and problems (theoretical and/or practical) learnt to be solved that concepts acquire meaning (Rodriguez Palmeiro & Moreira 2004). This does not imply neglecting the role of language and symbolisms in the conceptual construction since both of them are fundamental. It only means that the adaptive function of knowledge requires a central role for the ways the latter takes in the subject’s actions. “Rational knowledge is operative or it is not such knowledge” (Vergnaud, 1990).

In this referential and given a situation, behavior is directed by schemes that generate a sequence of actions that depend on the situation parameters. Vergnaud defines the scheme as “the invariant organization of action for a certain class of situations”, or as “an organized totality which permits to generate a class of different behaviors according to the particular characteristics of the situation”. Vergnaud surpasses the stereotyped point of view, stressing that “it is not conduct which is invariant but the organization of conduct”.

The Piagetian concept of scheme is central in this theory as it represents the building blocks that organize the conduct, consequently, the scheme is a totality consisting in:

- Goals and anticipations which permit to identify situations.
- Operative invariants (concepts-in-action and theorems-in-action) by means of which the subject recognizes the pertinent elements of the situation as well as the relevant information and puts forth propositions from which to make inferences.
- Rules of action of the “if...then” type which allow to generate a sequence of actions.
- Inferences or reasonings the subject makes in the situation.

Inferences are essential for the activation of the scheme in each particular situation since “a scheme is not a stereotype but a temporalized function of arguments which permits to generate series of different actions and of information gathering according to the values of the situation variables” (Vergnaud, 1990).

It is worth mentioning that given a new situation, several schemes may be successively or simultaneously evoked by the subject. This observation of the theoretical framework would provide clues to investigate the development of hybrid responses in which the subject mixes pre-scientific schemes with scientific ones, or else models with different limits of validity and context (Bravo & Pesa, 2005).

With respect to the process of conceptualization as object of cognitive development, Vergnaud believes that concepts acquire meaning through multiple situations and problems when the subject gradually selects relevant properties to constitute the concepts-in-action and the theorems-in action. When such properties can be explicitly expressed, they are turned into concepts. In this process, the linguistic expressions, symbols and symbolic representations help the subject achieve cognitive complexity.

Thereby the relevance of considering the concept as a triplet of three sets:

S: the situations that give sense to or explain the concept.
I: the set of operative invariants that determine the operationality of the schemes (meaning).
T: the linguistic and non-linguistic forms that permit to represent the concept and its properties (signifiers) symbolically.

Therefore, if conceptual development during learning is to be researched on, it is required to consider these three aspects simultaneously. With respect to this, a detailed study of the field of knowledge provides the teacher with a picture of the many operative invariants with which a given task may be sorted out and the possible operative invariants the student might use during the process of learning.
Figure 1 shows a diagram representing the concept of wave from this theoretical referential. It is shown that though the physical laws that account for the properties of mechanical waves are different from the laws explaining the properties of electromagnetic waves, the kinematics of electromagnetic waves is exactly the same as that of the mechanical waves (Eisberg & Lerner, 1985). Consequently, there are operative invariants and symbolic representations common to both models, a fact that proves to be very useful in the teaching practice both to introduce the subject through concepts already known by the student and to implement the use of analogies as well.

3- Didactic Proposal

A series of activities as a didactic proposal for the development of concepts regarding the phenomena of interference and diffraction of light is presented in the Annex of this work. The design and sequence of such activities lie on the learning approach of Vergnaud’s conceptual fields theory and on the results of previous investigations as well. (Ambrose 1999-a, 1999-b; Wosilait et.al. 1999, Colin & Viennot, 2002; McDermott et. al., 2002 and 2005; Maurines, 2010; Bravo & Pesa, 2011).

The theory of conceptual fields holds that concepts, procedures and symbolic representations are connected with each other and intermingled during the process of knowledge acquisition. The analysis of the electromagnetic wave concept shown in Figure 1 was taken into account in the design of the proposal.

3.1- Introductory Activities

These activities consist of a series of qualitative exercises of pencil and paper where some of the most common symbolic representations of a wave are used (Serway, 2005; Young & Freedman, 2009). In such exercises students discuss and think out in small groups under the teacher’s guidance and coordination about the superposition of waves of the same amplitude and frequency.

One of these activities consists in the use of an analogy, the interference of waves in water, to discuss the phenomenon of the interference of luminous waves of two point sources that emit in phase and at the same frequency. Many texts present this analogy when introducing the subject, taking into account that wave optics, or the wave theory of light, started from analogies such as these between optical phenomena and phenomena proper to wave movements known as the phenomenon of surface waves in liquids, or that of the acoustic waves that produces sound. On this occasion the analogy will be used to achieve explicitness and accuracy of the fundamental concepts. The activity is based on the use of diagrams of concentric circles drawn in acetate, representing the wave fronts emitted by a luminous source. The superposition of the diagrams permits to analyze the formation of lines of interference maxima and minima in the space surrounding two sources that emit in phase and at the same frequency, and the dependence of the lines of maxima and minima on the separation between the sources.

The objective of the introductory activities is to generate a group discussion about the questions posed in order to make explicit fundamental concepts of wave movement such as: wave phase, phase difference between two waves, wavelength, electric field intensity at different points of the plane at a particular instant of time or at a point of the plane at different times, wave front, wave superposition or wave interference and interference pattern. Moreover, the sequence of questions helps the teacher acting as guide to lead the students’ reasoning towards the conditions required to reach the interference pattern stability in space and in time, as a first approach to the concepts of temporal coherence and spatial coherence.

The concepts related to the performance of the eye, which acts as a sensor, are closely linked to the conditions required to achieve the interference pattern stability. The discussion on the relevance of the electric field intensity at different points in the space and at different times according to the wave model and the response of the eye to the intensity variation of the electric field, permits to determine and differentiate the “electric field intensity” and the “luminous intensity” concepts and to achieve the conceptualization of the “interference pattern” as the spatial distribution of luminous intensity maxima and minima.
Figure 1. Interpretation of the wave model from the Vergnaud’s theory
The study of the field of knowledge (Fig. 1) can show the teacher which operative invariants would not be available in the students’ schemes and what type of situations and/or symbolic representations can be conveniently added to promote the schemes construction during the learning. For example, it can be proposed to the students to design circle configurations on a slide, showing a phase difference with respect to other configurations on paper. This could be done to visualize interference and to think out about the interference pattern characteristics in sources that emit with a phase difference. In order to deepen the discussion about the interference pattern stability, computer simulations could be also added to show the advancement of wave fronts in different situations: two sources that emit in phase, two sources that emit with constant phase difference and two sources that emit with random time phase difference.

3.2- Prediction activities

Students are asked to predict what would be observed on the screen in an experimental system consisting of a light source, a double-slit system (or a single slit) and a white screen, when the source is on. Two alternatives for the source are considered: the use of a laser beam and an ordinary incandescent lamp. It is stressed that the slits dimensions and the spacing between them is on the order of $10^{-3}$ mm.

This stage aims at making evident the students’ operative invariants and their conceptions of the behavior of radiation since, within the theoretical framework underlying the proposal, they are considered to be key elements for the achievement of the new concepts. Previous investigations on this type of activities (Wosilait et.al. 1999; Mc Dermott et. al., 2002, 2005; Maurines, 2010; Bravo & Pesa, 2011) demonstrate that students’ predictions truly show their drawbacks to approach the situation from a new paradigm (wave optics). In general, three main types of responses are found: most of them show a reasoning that takes into account ray optics, other show a hybrid reasoning that mixes elements of geometrical optics and of wave optics; finally, responses which are partially correct from the wave model though incomplete regarding their justification. This last type of response is the least frequent and it corresponds to students that have managed to develop a scheme to deal with the situation from the wave model but who cannot make their reasoning explicit and are not able to relate concepts yet.

3.3- Experimental activities

These activities involve the observation of the diffraction and interference patterns by means of the experimental system presented in this paper, and the experimental study of the qualitative dependence of the patterns on aperture width, distance between slits and wavelength of the incident radiation, as well as the measurement of the laser wavelength using single slits, double-slit systems and/or diffraction networks.

The initial stage of the experimental activities is one of confrontation with experience and in some cases of conflict as well. This works as a motivating factor, leading the students to question the limits of validity of their pre-scientific models and to compare them with the capability of the scientific models. Indeed, most of the students are surprised by the contradiction arisen between their predictions and the experimental results. The main contradictions are generated by the incorrect use of the geometrical optics model and the lack of differentiation between the different features of the laser and those of the ordinary sources of light.

Thus, it is considered to be useful to add the emission characteristics (bandwidth, coherence length and time) of the different luminous sources as situations to be studied so that more meaningful concepts are acquired while the analysis of the models’ limits of validity is deepened.

At this point, it is of primary importance the teacher’s role to guide the students’ reasoning in their attempt to account for the experimental results. The teacher makes use of questions concerning both the model and the features of the experimental situation, trying that the students relate them.

For example, some questions may be: is the model of radiation that propagates in the same way as the waves represented by concentric circles adequate to explain what is observed on the screen, both for the laser beam and the incandescent lamp? Why? Can you fully express the limits of validity of the model of concentric circles? Could you say how would the circles be modified to represent an extensive source of white light? Where is the screen located in the diagram of overlapping concentric circles? Why is the intensity pattern seen on the screen placed on a line? What would the intensity pattern be like if it had two little circular holes instead of two thin rectangular slits? etc.
Using once more the analogy with the superposition of waves in water to explain the results found, permits to deepen and define the concept of interference “pattern” as well as the qualitative dependence of the interference and diffraction pattern on the distance between slits and the slits width.

It is both surprising and at the same time motivating for the students the visualization of the spatial configuration of a double-slit interference pattern with a laser source when dust chalk between the slit and the screen is scattered in the environment. Some students say that “the same as with the superposition of the circle diagrams is seen” or that they can see “the same lines of maxima and minima as with the acetates overlapped”.

At this point of the proposal, it is thought that the students have acquired a conceptual basis to approach with greater rigor the predictions of the scientific model and the limits of validity of such predictions. After the group discussions on the meaning of the different symbolic representations, it is assumed that the students could understand the problem better as well as deduce the relationships among the variables present in most texts of basic university level (Serway, 2005; Young & Freedman, 2009).

In the case of double-slit interference (Fig 2), the most common procedure consists in analyzing the conditions to produce constructive interference at a point on the screen, which is placed at a great distance from the slit. Thus, the conclusion is drawn that constructive interference is produced when the difference of path travelled by radiation up to the point causes the waves to reach that point with a phase difference that corresponds to a whole number of wavelengths.

\[ n \text{ sen } d = \pm \lambda, \ldots \pm 2, \pm 1, \pm 0 \]

Minimum: \( d \cdot \text{sen}\theta = \left( n + \frac{1}{2} \right)\lambda \)

Maximum: \( d \cdot \text{sen}\theta = n\lambda \)

\[ \text{Con } n = 0, \pm 1, \pm 2, \ldots \]

**Figure 2.**

In the case of single-slit diffraction (Fig 3), the interference of waves that arrive out of phase due to a difference of the path travelled up to a point on the screen is assumed as the cause for the occurrence of luminous intensity maxima and minima pattern. Likewise, the angles at which luminous intensity maxima and minima will occur can also be deduced. But where do these waves come from if only one slit is involved? In this case, the difficulty for the students is to imagine that the slit behaves as if it were a set of spherical wave emitters (Huygens’ principle). Indeed, none of the predictions carried out within this experimental system in previous investigations considered the wave optics model and they did not take into account the possibility of wave interference when they tried to explain the experimental results.

\[ a \cdot \text{sen}\theta = \left( n + \frac{1}{2} \right)\lambda \]

Central Maximum: \( a \cdot \text{sen}\theta = 0 \)

Minimun \( a \cdot \text{sen}\theta = n\lambda \)

Con \( n = \pm 1, \pm 2, \ldots \)

**Figure 3.**
Secondary Maximum:

With respect to the luminous intensity distribution, the concepts of scalar addition of waves are required to deduce the algebraic expressions that relate luminous intensity magnitude to the $\Theta$ angle, both in the analysis of double-slit interference and single-slit diffraction. The results predict a uniform distribution of luminous intensity for the double-slit interference pattern (Fig.2) and a non-uniform distribution of luminous intensity for a single-slit diffraction (Fig.3).

Turning back to the experimental results, detailed observation of the intensity pattern on the screen in a double-slit system (Figure 4) allows students, through group work under the teacher’s guide, to deduce that such pattern of intensities does not agree with the prediction represented in figure 2 and that in fact, it corresponds to the combination of the two effects: double-slit interference and the diffraction produced in each of the slits, which is also explained from the wave interference concept.

![Figure 4.](image)

From this stage onwards, students are able to carry out a quantitative analysis of the relationship between the different variables that take part in the model and to make measurements, either of the laser wavelength by knowing the system parameters or vice versa. They can also deal with experimental situations such as the luminous intensity pattern obtained by means of a diffraction network or analyze a CD or DVD performance when white light or a laser light falls on them, explaining the results quantitatively as well. All these are synthesis activities in which the relationships between concepts and the different situations that explain them are reinforced.

4- Final Considerations

The construction of a new paradigm, the wave optics, is a slow and complex process due to the characteristics of the cognitive processes and the complexity of the conceptual field, which is shown in Figure 1 diagram.

For example, some results (Mc Dermott & Heron, 2007; Bravo & Pesa, 2011) regarding the use of the activities proposed show that even though the analogy presented is useful to promote the discussion of different topics concerning the description of luminous waves and some of their properties, at a first instance, it does not prove to be enough so that the students relate concepts and organize them in a model to face the experimental situations. Difficulties in identifying the two slits with the two point sources of the concentric circles are still shown at the moment of making predictions. However, this fact is taken advantage of in the conflict situation when the predictions are compared to the experimental observations; at this point, analogy is used once more. The latter is carried out to deepen the discussion, in small groups, on the characteristics of the interference and diffraction patterns observed on the screen and their dependence on the system’s geometry and the features of the incident radiation.

This activity sequence, continuously leading the students from the situations to the analysis of concepts and symbolic representations, and vice versa, permits the progressive construction of the electromagnetic wave concept to account for the interference and diffraction phenomena. With this purpose, figure 1 works as guidance for the teacher to interpret how the student progressively incorporates operative invariants, and how the relationships between them and with the different situations and symbolic representations are developed. Figure 1 also makes it possible for the teacher to answer questions such as: Which operative invariants are not available in the schemes of the students? How could they be generated? Which ones should be explicitly mentioned and defined? What type of situations and/or symbolic representations would be adequate to introduce in order to promote their development?, etc.

Besides, experimental activities in small groups represent a significant didactic strategy in the process of conceptualization of the topic, since it involves a working environment favorable for the students to make explicit their operative invariants and models, as well as for discussion and meaning negotiation.
Moreover, the objectives proper to experimental activities contribute to the conceptualization of the wave model of light as they foster awareness of the different magnitudes of the variables involved, such as the slit separation and width, the laser wavelength and the angles of different intensity maxima and minima on the screen, affording inferences and predictions as regards the behavior of the distinct experimental systems. The discussion on the limits of validity of the model that explains the results is also favored, by providing quantitative criteria to analyze the validity of the approaches posed by different texts with the purpose of simplifying the model, such as great distances to the screen or small angles, in a given experimental situation (Alonso, 1981; Hecht, 1987, Young & Freedman, 2009).

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Annex

1- Introductory Activities: the electromagnetic wave model and the superposition principle

The following figure represents a plane electromagnetic wave that propagates in the x axis direction:

\[ E(x, y, z, t) = E_x \sin(kx + \omega t) \]
\[ B(x, y, z, t) = B_z \sin(kx + \omega t) \]

1.1- In groups, synthesize the main concepts and characteristics of this electromagnetic wave model. Compare it with the mechanical wave model.

1.2- Suppose the following graphs represent the electric field intensity variation in time of two luminous waves that fall at any point P on a screen.

a) Are waves 1 and 2 in phase at point P?

b) Draw the wave that results from the addition of waves 1 and 2. What is your conclusion?

c) Now consider the luminous intensity at that point. Does luminous intensity at point P vary in time?

1.3- Now suppose that the electric field intensity variation in time at another point Q is as it is shown in the following picture, i.e., the waves are out of phase a \( \pi \) angle.

a) Draw the result of the superposition of these two waves at point P. What is your conclusion?

b) What will luminous intensity at that point be like? Is this value maintained at different times?

1.4- Do an analysis similar to the previous ones when waves 1 and two are out of phase an angle between 0 and \( \pi \).

1.5- The wave trains of a luminous point source can be represented by means of concentric circles in the same way wave fronts generated in water due to disturbance on the water surface are represented.

Use the diagrams provided (on paper and slide) to represent two emitting luminous sources and explain:

a) What do the concentric circles represent? Are they E(t) and E(x) diagram or any other type of diagram? Explain.

b) What does the distance between one circle and another one represent?

c) How could you know if the two sources are emitting in phase?
d) What happens at those points of the plane where two circles cross over each other when the waves produced by the two sources overlap?

e) In what way does the separation between sources influence on the formation of lines of interference maxima? Explain.

f) Is a pattern of luminous intensity formed if $S_1$ emits radiation at a constant phase difference with respect to the source $S_2$? How is it represented using concentric circles?

g) How could you cause the pattern of bright and dark stripes to remain constant in space and in time? Analyze and explain how wave fronts advance.

1.6- Explain why bright and dark stripes at points P, Q and R of the following graph are formed. Explain what type of diagrams represent the “waves” from $S_1$ and $S_2$ up to point P and the hypotheses considered in this graph.

2- Activities of Prediction

2.1- Consider an experimental system consisting of a source of laser light, two small slits (separated by ≈1mm) and a screen

a) What would you expect to observe on the screen when the source of laser light is on? Explain your answer.

a) What would you expect to observe on the screen if the laser source is changed for an ordinary incandescent lamp? Explain your answer.

c) What would you expect to observe in the previous situations if the spacing between slits is changed (increased or diminished)? Explain your answer.

2.2- Consider an experimental system consisting of a source of laser light, one small slit (≈0,1mm width) and a screen.

a) What would you expect to observe on the screen when the source of laser light is on? Explain your answer.

a) What would you expect to observe on the screen if the laser source is changed for an ordinary incandescent lamp? Explain your answer.

c) What would you expect to observe on the screen in the two previous situations if the slit is changed for a wider one (greater than 1mm)? Explain your answer.

3- Experimental activities

3.1- Confrontation of predictions with experience. Discussion of the results.

3.1.1- Are the predictions previously carried out satisfied? Why? On the basis of the model studied, explain the observations and indicate all the assumptions made.

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3.1.2- Search for information on the mechanism of emission of the main sources of light you used in the lab practice (include the laser). Make a comparative diagram of the emission mechanism and the type and range of radiation emitted.

3.1.3- Is the model of plane, infinite and monochromatic electromagnetic wave adequate for the radiation emitted by each one of these sources? Which one would be the adequate model for each case? Explain.

3.1.4- What could you say about the property of monochromaticity and coherence in the case of these sources? As they are extensive sources, what is the effect?

3.2- Double-slit interference

3.2.1- Using a laser source, measure the position of the maxima for a two-slit interference pattern. Are the theoretical predictions satisfied? Explain.

a) Calculate the wavelength of the laser used, taking into account the spacing between the slits.

b) Is the intensity of the interference maxima observed on the viewing screen the same for all the maxima? What does the model considered predict in this respect? Explain.

3.3- Single-slit diffraction

3.3.1- Consider the experimental system consisting of a single slit illuminated with laser light:

a) What are the characteristics of the pattern observed on the screen? What is the difference with the pattern obtained with double slits? Explain.

b) Measure the position of the maxima and estimate the uncertainty range of the measurement. Are the theoretical predictions satisfied? Are the approaches of the model valid? Explain.

c) With the pattern obtained for a certain position, calculate the value of the slit width with the least possible measurement error. How would the pattern of diffraction be modified if the slit width changes? Justify your answer quantitatively.


3.4.1- Consider the experimental system consisting of a diffraction network illuminated with laser light:

a) Which are the characteristics of the pattern observed on the screen? What is the difference with the pattern obtained with double slits? Explain.

b) Measure the position of the maxima and calculate the slit separation and its uncertainty interval.

c) Calculate the number of lines per cm of the network.

3.4.2- Change the diffraction network for another one with greater or smaller number of lines per cm and repeat the previous activities.

3.4.3- A CD works as a diffraction network by reflection. Use the laser to obtain the diffraction pattern and calculate the number of tracks per cm for a CD and a DVD.

3.5- Synthesis activities

3.5.1- Explain why colours are seen when white light falls on a CD.

3.5.2- In order to increase the resolution power of a spectroscope what is more convenient to use, a prism of n=1, 51 refraction index or a 500 lines per mm refraction network?

3.5.3- Under which conditions could the interference and diffraction phenomena be observed by means of conventional sources? Explain.

3.5.4- Synthesize the concepts of spatial coherence and temporal coherence. Relate these concepts to the conditions required to observe stable interference patterns.

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Visualizing the Profile of Waves: New Experiments with the Ripple Tank

Fabrizio Logiurato and Luigi Gratton, Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo, Trento, Italy

Abstract

We propose a simple and cheap modification of the usual ripple tank. Our device could be constructed by students in their school laboratory. The lighting in the new apparatus differs from the usual arrangement: the light is somewhat oblique with respect to the water surface and a system of screens with holes and slits is placed at the bottom of the glass tank. This allows us to select small portions of the water surface to be illuminated. In this way our modified ripple tank gives us the possibility to make some new experiments and to explain by further examples the properties of waves. For instance, on a screen we can observe the profile of a sinusoidal wave. When we produce a wave packet, we can see as it changes while it is travelling on the water. This tool allows us also to study beats and new visualizations of interference and diffraction from slits.

1. Introduction

The ripple tank usually consists of a container with a transparent bottom filled with a thin layer of water. A source of light illuminates the water surface from the top and the water is mechanically perturbed in order to produce regular waves. With the water crests and troughs acting as converging and diverging lenses, the surface configuration is reproduced on a screen.

We propose a simple and cheap modification of this tool. The lighting in our apparatus is oblique with respect to the water surface and a system of screens with holes and slits is placed at the bottom of the glass tank. Such a modified ripple tank allow us new visualizations of waves.

For instance, on a screen we can observe the almost sinusoidal profile of a travelling wave, in order to analyze the relation between period, wavelength and speed. We can also observe the profile of a stationary wave produced for interference between an incident wave and its reflected wave, analogous to that formed on a vibrating string in the same circumstances. With the construction of two plane waves having frequencies almost similar, we can study the interference between the two waves and the formation of beats. When we produce a wave packet, we can observe its dispersion, as its width grows and its profile changes while it is travelling on the water. It is possible also to make some observations regarding the amplitude and intensity of diffraction and interference patterns, which are not possible with the original ripple tank.

2. Some Example

We can consider as first approximation the wave produced by the vibrations of the ripple tank bar as a sinusoidal wave. The observation of its profile is obtained in the following way: we set a black cardboard on the bottom of the ripple tank, on the external part of the glass container (Fig. 1). The cardboard covers the whole bottom except for a thin slit a few millimeters wide.
Figure 1. a) Bottom of the ripple tank covered by a black cardboard. A lamp set under the ripple tank illuminates transversally and in grazing way the slit. b) A black adhesive tape forms the sharp edge of the slit. The light of the lamp goes through such a slit.

Such a opening is transversely set with respect to the bar that produces waves and it extends itself for the whole ripple tank. The cardboard is sticking to the bottom by some adhesive tape. A black adhesive tape also has the purpose to make sharper the edges of the slit. A halogen lamp set under the ripple tank illuminates transversally and in grazing way the slit. In Fig. 2 the profile of the sinusoidal wave is projected on a white screen placed on the opposite part of the lamp, parallel to the direction of the wave propagation. When a ray of light passes through the slit and it meets a crest it is translated by refraction from its initial direction in a higher degree than when it meets a throat, since the ray must cross a higher thickness of water. Therefore the alternation of crests and throats produces a vertical oscillatory motion of the ray. Actually, we also have a horizontal motion of the ray, due to the fact that in the passage from the crest to the throat the ray of light meets the water surface at different angles. Such an effect can experimentally be verified using a small laser pointer.

Figure 2. a) A white screen is set on the opposite part of the lamp, parallel to the direction of the wave propagation. b) The profile of a sinusoidal wave on water projected on such screen.

Besides, the rays that go out from the light source are not parallel each other and this introduces a further deformation on the light projection of the sinusoidal wave. Nevertheless, all these deformations result negligible for a wave of small amplitude, and if we observe just the part of wave more distant from the lamp, where the wave front of light illuminating the water surface of interest is almost plane. One can think to obviate these defects imagining a more complex system of illumination, but for our educational aim we consider the simple device here introduced enough.

“With our apparatus it is also possible to observe the evolution of a wave packet. We could consider a wave packet as a perturbation of the water surface located in the space and constituted by the sum
of many waves with different frequencies (Feynman et al., 1963; French, 1971). The wave components constructively overlap themselves in a small region, and destructively elsewhere. With the modified ripple tank we can illustrate the principal physical characteristics of a packet: as it changes its form while travels, as the waves inside the packet propagate with different speed in comparison to its center, as the wave packet disperses during its propagation because of the different speed of the waves that form it. In the picture of Fig. 3a the perturbation of the water surface is obtained dropping on it one water drop.

Figure 3. a) Profile of a wave packet. The perturbation of the surface is caused by water drops falling from a dropper. b) Visualization of beats between waves with different frequency.

The formation of a wave packet for interference can be effectively illustrated by observing the phenomenon of beats: the interference between two sinusoidal waves which do not differ too much in frequency. In our apparatus the two perturbations are originated one from the usual regular vibration of the bar and the other contemporarily setting the same bar in oscillation with a little push of our hand. In this way the bar vibrates with more frequencies. Therefore we can see on the screen the formation of beats: two waves caused by the vibration of the bar alternatively interfere constructively and destructively (Fig. 3b). In reality, the induced oscillation is a damped oscillation, therefore with amplitude which tends to zero and having more frequencies. In fact, the sinusoidal wave turns out modulated with an increasing period, until it becomes a wave with constant amplitude.

Also with experiments of diffraction from a single slit, or interference from two slits, our apparatus can provide new interesting images and new suggestions for teaching wave physics. In that case, as you can see in Fig. 4a, the slit on the cardboard is placed parallel with respect to the bar generating waves. Moreover, now the lamp is behind the bar and the screen is parallel to the slit (Fig. 4b).

Figure 4. a) In order to study interference or diffraction from one or two slits, now the openings of the cardboard are set parallel to the bar generating waves. b) The lamp is placed behind the bar. The screen is parallel to the slit of the cardboard.
For instance, with a thin slit we can get a section of our interference picture in which the maximum and minimum peaks of the amplitude are well visible (Fig. 5a). We must notice that what we observe directly on the screen is not the intensity but the amplitude of the interference, the intensity is given by the square modulus of the amplitude. Moreover, the maximum and minimum peaks don’t follow the usual law on the interference. In fact, being the section of the interference on the water near to the slits, we expect the Fraunhofer approximation does not hold (Jenkins & White, 1957). For instance, the central maximum almost has the same height of the others. Finally, with wider openings on the cardboard, we can get new spectacular and amazing 3D images of the interference, the picture of Fig. 5b is an example of those.

Figure 5. a) Section of interference in which we can see the maximum and minimum peaks of the amplitude. b) On the right, 3D picture of interference from two slits obtained with a large opening in the cardboard.

3. Conclusions

We have proposed a small change of the traditional ripple tank, cheap and easily realizable by the students themselves. Such a ripple tank allows to realize further and interesting experiments with respect to those usually introduced. For example, the visual observation of beats among waves is difficult to get with experiments with strings or springs, like also the propagation and the dispersion of wave packets, or the visualization of sinusoidal waves. All of that is easily realizable with our simple modified ripple tank.

For elementary textbooks about physics of water waves you could see Barber (1969) and Bascom (1964). You can find some other original example about teaching of wave physics in Logiurato (2012), Logiurato and Danese (2010) and Logiurato et al. (2006).

References

Electric Circuits in The Heureka Project: Multiple Representations

Irena Dvorakova, Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague

Correspondence concerning this article should be addressed to Irena Dvorakova, Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague, V Holešovičkách 2, 180 00 Prague 8, Czech Republic. E-mail: irena.dvorakova@mff.cuni.cz

Abstract

The main goal of teaching physics in The Heureka Project is developing the scientific ability of students in all levels of schools. We have more than twenty years of experience with teaching using different active methods of learning. This paper describes one of them – a method of building the concept of electric circuits and its different representations in students’ minds. This method is used by teachers in lower secondary schools (ages 12 to 13 years), namely teachers who are involved in The Heureka Project. This paper shows the gradual process which helps students to really understand this concept and gives them the ability to solve different problems concerning electric circuits. Peer to peer interaction forms an integral part of this approach. Students discuss, explain problems to their classmates, and teach each other. Our method uses different representations of an electric circuit and the description of its function. In this paper we show several concrete examples of the tasks, which are solved during the learning process and also some students’ solutions, to enable other teachers to use these activities in their schools.

Keywords: multiple representations, electric circuits, active learning

Electric circuits in The Heureka Project – multiple representations

Introduction

The development of students’ scientific ability is one of the main goals of teaching/learning physics at schools all over the world. The term “scientific ability” is used for describing processes and methods that scientists use when constructing knowledge and when solving experimental problems.

Scientific ability is a very complex skill; the ability to represent information in multiple ways is one part of it. The Rutgers Physics and Astronomy Education Research group [Etkina, Van Heuvelen, 2006] shows three sub-abilities which help to make this multiple representation strategy productive for reasoning and problem solving:

• The ability to correctly extract information from a representation;
• The ability to construct a new representation from another type of representation;
• The ability to evaluate the consistency of different representations and modify them when necessary.

Students can use the multiple representations in different topics - for example, motion diagrams and free-body diagrams in Mechanics, and ray diagrams in Optics.

“Simple electric circuits” is one of the traditional curriculum elements in physics at lower secondary schools. Students usually solve problems concerning light bulbs and their behaviour depending on the state of switches or sometimes they build real electric circuits; nevertheless, they have many misconceptions. Students have problems with understanding and correctly applying the concept of a complete circuit [Osborn, 1983].

In the study concerning the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) it was found that two thirds of high school students knew that a light bulb had two connections, but one-third believed that there was only one connection which was located at the bottom of the bulb. Students were able to translate easily from a realistic representation of a circuit to the corresponding schematic diagram. However, students had difficulty making the reverse translation [Engelhardt, 2004].
The results from different research studies show that students need more possibilities to work with real electric circuits. They need to understand multiple representations of the circuit to deeply understand its behaviour:

Many students have no observational or experiential base that they can use as a foundation for constructing the formal concepts of introductory electricity. This deficiency in background can be a serious handicap when students attempt to relate electrical concepts to real circuits. In a survey of a large calculus-based physics class, we found that 60% of the students lacked previous experience with simple circuits. Only about 15% indicated that they had some familiarity with batteries and bulbs. [McDermott, 1992]

In the final part of this research report the authors suggest how this situation could be remedied:

There is a need for instructional materials that foster the active mental participation of students in the learning process. The development of curriculum that fulfils this need should be guided by knowledge of what students know and can do, rather than by assumptions about what they should know and should be able to do. [McDermott, 1992]

In the Heureka project we have developed a five-step methodological sequence, which helps students to build the concept of electric circuits using multiple representations.

The Basic Information about the Methodological Sequence

This instructional approach is an example of the method used in teaching physics in The Heureka Project. It takes 5 consecutive lessons lasting r 45 minutes each. It is intended for pupils approximately 13 years old, who are being introduced to the topic of electric circuits for the first time at school. For the purpose of this article the results of 25 students were recorded in June 2012, but as mentioned before, these were “normal lessons” that have been used with students for many years already, and not specially adapted only for this research.

Aims:

• To elicit pupils’ current ideas about electric circuits, and to identify their possible misconceptions.
• To help them reconstruct their ideas which differ from the correct explanation.
• To teach pupils several different representations of an electric circuit (a real connection, a circuit diagram, a table describing the state of switches and bulbs).
• To teach pupils to solve three types of tasks concerning electric circuits.

This teaching-learning sequence has five steps:

• The first step: FINDING PRECONCEPTIONS
• The second step: CHECKING IDEAS and THEIR RECONSTRUCTION (if necessary)
• The third step: DISCOVERING PROPERTIES OF AN ELECTRIC CIRCUIT
• The fourth step: Determining Properties of Working Electric Circuits and Interpreting A Circuit Diagram
• The fifth step: SOLVING THREE TYPES OF TASKS WITH CIRCIRTS

The topic Electricity is reintroduced two years later in the 8th class. Pupils in this class recognize the concepts of current, resistance and voltage, find Ohm’s law using water model of an electric circuit and calculate the total resistance of series and parallel resistors. They are also guided in developing more complex concepts, such as electric power and energy.

In this paper we concentrate only on the first part of the teaching of electricity, at the first ideas about the simple electric circuit. During the first lesson (on the 1st – 3rd step of the methodological sequence) students work with a worksheet (see Appendix 1; only several tasks from the worksheet are included in this paper). During the second lesson, students investigate the 4th step of the sequence. The three types of tasks with circuits (the 5th step) are solved in the last three lessons.
The First Step: DETERMINING PRECONCEPTIONS

Worksheet Task 2: Draw your idea of how to make the bulb light. (You have only the bulb and battery, nothing else).

In this step students are not allowed to actually connect the elements to try to make the bulb shine. They only imagine how to do it and draw their ideas. (Note: We use the batteries with two longer terminals, see Figure 3.)

The ideas students drew on their worksheets could be divided into five groups - see Table 1.

Table 1

Answers for the Worksheet task 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Type of answers</th>
<th>Number of answers</th>
<th>%</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>correct</td>
<td>9</td>
<td>36%</td>
<td><img src="image1" alt="Correct Answer" /></td>
</tr>
<tr>
<td>B</td>
<td>the bulb touches only one pole of the battery</td>
<td>6</td>
<td>24%</td>
<td><img src="image2" alt="Bulb Touching One Pole" /></td>
</tr>
<tr>
<td>C</td>
<td>the bottom point of the bulb touches both poles of the battery</td>
<td>4</td>
<td>16%</td>
<td><img src="image3" alt="Bulb Touching Both Poles" /></td>
</tr>
<tr>
<td>D</td>
<td>the lateral point of the bulb touches both poles of the battery</td>
<td>3</td>
<td>12%</td>
<td><img src="image4" alt="Bulb Touching Both Poles - Lateral" /></td>
</tr>
<tr>
<td>E</td>
<td>confused</td>
<td>3</td>
<td>12%</td>
<td><img src="image5" alt="Confused" /></td>
</tr>
</tbody>
</table>
The Second Step: CHECKING IDEAS and THEIR RECONSTRUCTION (if necessary)

Worksheet Task 3: Try your idea. Was it correct? Write whether the bulb shines.

Worksheet Task 4: If the bulb doesn’t light up, try to play with it and make it light. Then draw the arrangement of a battery and a bulb for which the bulb lighted.

In the second step each pupil can check his previous idea. He can play with a bulb and a battery (without wires). He tries to make the bulb shine and evaluates whether his previous opinion was right or not. What is important is the fact that the correctness or incorrectness is determined by experiment, not by the teacher’s authority.

Figure 1. Does it shine?

Almost all students whose ideas were not correct (students from the groups B, C, D) were successful now. They discovered the right solution. Only three pupils from group E had difficulties with this task.
The Third Step: DISCOVERING PROPERTIES OF AN ELECTRIC CIRCUIT

Worksheet Task 5: *Competition for pairs*: Connect the bulb to the battery through as many things as possible at the same time so that it shines.

*Record your findings*. We were able to make the bulb shine when connected to the battery through ..................pieces at the same time.

In this step, pupils find the basic properties of the electric circuit. This activity is very popular with children. Pupils are competitive, so they like it very much. Usually they are able to make the bulb shine using 20 – 30 pieces at the same time.

![Figure 2. Concentration during a competition](image2)

![Figure 3. Non-traditional electric circuit](image3)

Worksheet Task 6. *Sketch how the experiment looked* *(using 4 – 5 pieces is enough)*

Students did not have problems with this task. Several students’ solutions are shown below.

![Figure 4. Several students’ solutions of the non-traditional electric circuit](image4)
The Fourth Step: DETERMINING PROPERTIES OF WORKING ELECTRIC CIRCUITS and INTERPRETING A CIRCUIT DIAGRAM

At the beginning of the second lesson during a teacher-students’ discussion, students determine necessary conditions for lighting the bulb at the competition in the last lesson. The teacher must not tell students those conditions; students are able to formulate them independently.

Necessary condition for lighting the bulb – students’ answers:

- All things are conducting.
- All things are in contact.
- All things are connected in a complete loop. Each of two terminals of the bulb is connected to a different terminal of the battery through a continuous conducting path.
- The bulb and battery are in working order.

After this discussion the teacher shows the pupils circuit diagrams to represent circuits and also tables for describing the state of switches and bulbs. The brightness of individual bulbs is not important at this level.

In the second part of this lesson pupils work in groups. They work with real bulbs, switches and batteries and build assigned circuits.

Students fill in the tables and then connect bulbs and switches to check their hypothesis. Students like these problems because they work, think, and discuss ideas together.

Example:

A circuit diagram of a series electric circuit and the table describing its behaviour.

(Z1 and Z2 means bulbs, S means switch, 0 means an open switch or a dark bulb, 1 means a closed switch or a shining bulb)

![Diagram of a series circuit](image)

<table>
<thead>
<tr>
<th>S</th>
<th>Z1</th>
<th>Z2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Figure 5. An example of a schematic diagram of a series circuit and the table describing its behaviour.*

As you can see in the photo of the blackboard (Figure 6), pupils are able to solve rather complicated problems very soon. In task number 4 there is a short connection – the behaviour of the bulb 2 is very surprising for students. The teacher has to explain it!

*Figure 6. The first five tasks concerning simple electric circuits, their diagrams, and tables.*
The Fifth Step: SOLVING THREE TYPES OF TASKS WITH CIRCUITS

- The first type:
  Start from the circuit diagram. Fill in the table and build the circuit.
- The second type:
  Start from the table (or the verbal description of the function of the circuit). Draw the circuit diagram and build the circuit.
- The third type:
  Start from the real circuit. Draw the circuit diagram and fill in the table.

During the third lesson students continue solving the first type of tasks with circuits. They work in groups of three or four; they work with real bulbs, switches, and batteries. Students start from the circuit diagram, draw the table and make the connection for more complicated circuits. They find the function of a two-way switch.

![Figure 7. A more complicated task concerning simple electric circuits, its diagrams and tables.](image)

![Figures 8., 9. Building electric circuits](image)

Students are usually very active when “playing” with bulbs and batteries. They are able to help (and to teach) each other.
The fourth lesson is focused on the second type of tasks with circuits: Students start their work from the table (or the verbal description of a function of the circuit) and they draw the circuit diagram and build the circuit. This type of task is much more difficult for students. Sometimes they need help from other students or from a teacher. Two examples of this task are in Figure 10.

![Figure 10. From the table to the circuit diagram](image)

The fifth lesson of this methodological sequence is focused on the third type of tasks with circuits: One student from each group devises some circuit diagram and connects the real circuit which corresponds to his diagram. The others then examine this real circuit and have to draw the diagram and fill in the table. The author of the task checks their solutions. This problem is difficult both for the student who prepares the task and for the others who solve it. The discussion in a group is usually very intense.

**Continuation of the Topic of Electricity**

The five lessons described in previous paragraphs contain the basic knowledge concerning electric circuits which students (about 12 - 13 years old) should know. This topic is reintroduced two years later. Older students recognize concepts of current, resistance and voltage and find Ohm's law using a water model of an electric circuit; moreover, they calculate the total resistance of series and parallel resistors. They are also guided in developing more complex concepts, such as electrical power and energy.

**Conclusions**

From my own long time experience I can say that the approach in which students themselves formulate hypotheses, find the properties of bulbs, and solve different problems helps them to deeply understand the concept of electric circuits.
References


Appendix

Worksheet - electricity

1. Sketch what the bulb and battery look like.
2. Draw your idea of how to make the bulb light (you have only the bulb and battery, nothing else).
3. Try your idea. Was it correct? Write whether the bulb shines.
4. If the bulb doesn’t light up, try to play with it and make it light. Then draw the arrangement of a battery and a bulb for which the bulb lighted.
5. Competition for pairs: Connect the bulb to the battery through as many things as possible at the same time so that it shines.
6. Record your findings. We were able to make the bulb shine when connected to the battery through .......................pieces at the same time.
7. Sketch how the experiment looked (using 4 – 5 pieces is enough)
8. Your picture probably wasn’t neatly arranged; it would be difficult to print it to the text book. Try to draft a simpler way of illustration.
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The Learning of the Colour Phenomena: the Effects of a Teaching Strategy Designed to Favor a Change in the Way of Learning

Bettina Bravo, CONICET - Engineering Faculty, UNCPBA. Av. Del Valle 5737, Olavarría, B. A, Argentina  
Marta Pesa, Physics Department, FCEyT, UNT Av. Independencia 1800, Tucumán, Argentina  
Juan Ignacio y Pozo, Basic Psychology Department, UAM, Campus de Cantoblanco, Madrid

Abstract

This work studies the learning experience in students from secondary education when different innovative and traditional teaching proposals are implemented in the classroom. This work was carried out in two 32 and 35-student courses between the ages of 13 and 14, from educational institutions in the city of Olavarría (Province of Buenos Aires, Argentina). A factorial intergroup design of two non-random groups with measures pretest-posttest—posttest-delay, with a quasi control group was implemented. The influence and interrelation of independent variables (teaching moment: pre, post and delay; teaching proposal: both innovating and traditional, and response category) are studied upon the dependent variables represented by the probability with which the groups of people use different conceptions. The results reveal that traditional teaching does not encourage substantial changes in the students’ way of knowing (who use an intuitive knowledge after instruction). Students who underwent this study experienced a gradual change in the conceptual model they employ to explain vision and implicit principles guiding how they conceive such phenomena. The results obtained in this research evidence that it is possible to encourage Science learning in Secondary Education regarding this process as a substantial change in the way of knowing, which implies the gradual change from an intuitive knowledge to another more coherent with science.

Keywords: secondary education; learning, teaching, Physic, colour phenomena

Introduction

Many research works have studied the ideas students from different ages have as regards vision and the vision of color (Anderson & Kårrqvist 1983; Bravo y Rocha 2008; Bravo, Pesa y Pozo 2010; Chavet 1993; Feher & Meyer 1992; Galili & Hazan 2000; Guesne 1984; Verkerk & Bouwens 1993; Viennot 2001). Most of them have evidenced that, even after formal teaching, students from different educational levels tend to explain that “we see because we have eyes” and that “color is a property of objects”. Therefore, they employ ideas, models and intuitive conceptions on the basis of reductionist rather than systemic ways of reasoning, leading to phenomena explanations contrary to scientific accounts.

In this sense, scientifically it is conceived that in order to see an object and its color, the light reflected by it must fall on the observer’s eye to stimulate his visual system. The cornea-crystalline behaves as a thin lens producing the convergence of incident light, resulting in the image formation in the retina, where photosensitive cells are located. When light falls on them, complex chemical and biological processes occur causing the emission of nervous stimuli. Electrical pulses reach the brain where, through the cognitive processing of that information, the representation of what we see and its color are engendered (Monserrat 1998; Falk, Brill & Stork 1990; Gregory 1990). From these models, it must be assumed that light, the visual system and the object are part of a system and that the phenomena explanation in the science context “is just possible” if they are recognized in an integral relation arising from multiple interactions and processes among them.

In this context, it becomes essential to question about, why, despite formal education, do not students seem to learn the ideas proposed by science? Why are there so many difficulties to build scientific models in relation to visual perception phenomena? What type of learning does the construction of such models involve?
The theoretical perspective we adopt here implies conceiving scientific and intuitive knowledge as two ways of knowing, two substantially different ways of “seeing” and interpreting the world, which present implicit different characteristics. These differences would be related not only with the explicative model (and thus the idea, the conception used in one or another context), but also with the conceptual, ontological and epistemological principles that characterize each way of knowing. These principles would implicitly guide the way different phenomena are interpreted and conceived in each context, as well as the ways of reasoning activated when giving an explanation (Pozo 2001). Table 1 describes the explicative models, underlying principles (Pozo y Gómez Crespo, 1998) and ways of reasoning (Salinas de Sandoval y Sandoval 1996) connected with each way of knowing.

Table 1. Explicative models and ontological, epistemological and conceptual of both intuitive and scientific knowledge (adapted and adopted from Pozo y Gomez Crespo, 1998).

<table>
<thead>
<tr>
<th></th>
<th>INTUITIVE KNOWLEDGE</th>
<th>SCIENCE’S KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explicative Model</td>
<td>We see because we have eyes. Color is a matter’s property</td>
<td>To see an object and perceive a color, the light reflected by object must fall on and stimulate the observer’s visual system. This stimulation implies complex physical, chemical, biological and psychological processes.</td>
</tr>
<tr>
<td>Ontological Principle</td>
<td>State: interpretation of the world in the matter’s state unconnected among themselves.</td>
<td>System: phenomena are interpreted in terms of complex relations that form a system.</td>
</tr>
<tr>
<td>Epistemological Principle</td>
<td>Naive realism: reality is just as we see it, what is not perceived, is not conceived.</td>
<td>Constructivism: it is believed that science, composed by alternative models, allow interpreting reality but they are not reality itself.</td>
</tr>
<tr>
<td>Conceptual Principle</td>
<td>Fact and datum: phenomena and facts are described in terms of properties and observable changes.</td>
<td>Interaction: the bodies’ properties and phenomena are interpreted as a system of relations of interactions.</td>
</tr>
<tr>
<td></td>
<td>Monoconceptual: it is supposed that phenomena depend on only one variable</td>
<td>Pluriconceptual</td>
</tr>
<tr>
<td></td>
<td>Non-systemic: mutual effects are not considered among the elements involved.</td>
<td>Systemic</td>
</tr>
<tr>
<td></td>
<td>Reductionist: properties are more valued than the functions of the elements involved in the phenomena.</td>
<td>Non-reductionist</td>
</tr>
</tbody>
</table>

From what we have detected in previous research work (Bravo y Rocha 2008; Bravo y Pesa 2005) these models of explaining vision and color (both scientifically and intuitively) described in Table 1, would represent the extremes in a continuum where students usually move in during the learning process of science when formal teaching intentionally encourages an ontological, epistemological and conceptual change.

In this sense, such previous research allowed detecting four different ways students employ with a higher frequency to account for vision and color as teaching progresses. Table 2 shows these models of knowing grouped in four categories, which are characterized by the underlying explicative model, by ontological, epistemological and conceptual principles and their related ways of reasoning.
Table 2. Characterization and exemplification of the ways of knowing found.

<table>
<thead>
<tr>
<th>Category I: IDEAS BASICALLY INTUITIVITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conception characterization: elements involved in vision (light, objects, eyes) are partially recognized; interactions among them are not recognized. Perceptual phenomena are explained in terms of observable facts and from information derived mainly from the senses. Underlying principles: States-Fact or datum-Naive realism. Reasoning: reductionist, non-conceptual, non-systemic. Example: objects are seen because we watch with our eyes and they are seen in indifferent colors because they were painted that way.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category II: INTUITIVE IDEAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conception characterization: linear causal relations are recognized among variables. A passive role is given to the visual system and the object and it is recognized that it is necessary for the light to illuminate the object the object to see it. Color is a consequence of the characteristics of incident light. Underlying principles: Simple linear causality-State-Naive realism. Reasoning: reductionist non-systemic. Example: we see objects because light illuminates them and with our eyes we can see them. If we illuminate an object with a red, we will see it red.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CATEGORY III: IDEAS COHERENT WITH SCHOOL SCIENCEALTHOUGH INCOMPLETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conception characterization: interactions between light and matter are recognized as a cause of perception. A more passive role is given to the visual system (just seeing). Incomplete ideas are employed, although content in the context of school science. Underlying principles: multiple linear causality. Process: Process of overcoming naive realism. Reasoning: pluri-conceptual non-systemic. Example: we see objects because they reflect part of the light that illuminates them and, with our eyes, we can see them. An object is seen red because it reflects red light and it absorbs the other components of the incident light.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CATEGORY IV: SCHOOL SCIENCE IDEAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conception characterization: interactions light-object (absorption and reflection and light reflected visual system). Abstract models are employed to interpret and explain perceptual phenomena. Underlying principles: System-interaction-Overcoming naive realism. Reasoning: systemic, pluri-varied, non-reductionist. Example: we see because light reflected selectively by the objects falls on the eye and stimulates the visual system producing complex processes that enable seeing the object. We see objects of different colors because they absorb and reflect light with different characteristics. According to the spectral characteristics of the light that falls on the eyes, certain processes occur in the visual system that enable perceiving a color.</td>
</tr>
</tbody>
</table>

Science learning as regards vision and color would entail conceiving such phenomena in terms of the underlying ideas of categories III and IV, rather than I and II. This involves:

- Going beyond the naïve realism to relate intuitive ideas with scientific ones, recognizing them as different ways of interpreting the world surrounding us, from which explanations can arise with different levels of complexity and contextual validity. This is a complex change that requires a gradual revision of epistemological assumptions underlying intuitive knowledge and a reinterpretation of previous experience (Vosniadou and Brewer 1994). Such change would be gradual as formal scientific education advances.

- Going beyond the ontological restrictions imposed by intuitive ideas and appropriating the principles implied in the construction of scientific knowledge. The main problem of learning processes that call for a change of ontological categories (as in the case of color) comes from the difficulty of reinterpreting phenomena in terms of processes of interaction, as it goes “against” the intuitive tendency to interpret them within the causal linear and unidirectional relations (Chi 2002; Villani and Pacca 1990; Viennot 2001). During the learning process, the first important ontological change to be carried out will imply conceiving phenomena in terms of processes rather than states. The second radical change entails learning to interpret phenomena in terms of systems (Pozo y Gómez Crespo 1998).
Going beyond the conceptual restrictions imposed by the ideas built intuitively and gradually appropriate the principles implied in the construction of scientific knowledge, which involves overcoming the principle of “fact or datum” to accept the interaction as a way of interpreting phenomena. Here the change will also be gradual, involving the construction of ways of knowing “intermediate” (between the initial knowledge and school science) going from explaining phenomena in terms of simple and multiple linear causalities to conceiving them in terms of processes of interaction (Pozo y Gómez Crespo, 1998).

However, how can it be taught to favor such learning? Why does not traditional education seem to favor it?

When the phenomena of perception vision are traditionally dealt with in science lessons, a discipline analysis is usually carried out from a biological or physical perspective. From the former, the visual system physiology and mechanism are mainly treated to explain the vision of an object and color perception (chromatic vision), without (or only superficially and descriptively) considering the processes taking place beyond the observer related with the interaction light-matter (absorption, transmission and reflection), without which perceptive phenomena would be impossible. As for the physical perspective, the spectral nature of light and absorption, reflection and selective transmission processes of objects when radiation affects them are mainly considered. But they do not deal (if they do, it is from a brief description) with the importance of the visual system in perceptive processes, without which they would not take place (Gallili and Hazan 2000; Viennot 2001). In turn, the development of these topics is often limited to the description of phenomena, facts or data, rather than their interpretation and explanation from the models proposed by science. Such models are usually explicative, transmitted by the teacher, but their use (and the development of its abilities) in different contexts is not generally encouraged (Bravo 2008). The prevailing methodology is usually expository, where the teacher “explains science” through master lessons, disregarding students’ previous ideas and the nature of knowledge previously shared. Science learning is bound from this perspective to memorization of scientific knowledge rather than to interpretation. Consequently, evaluation seeks the reproduction of what was “learnt” in class, asking students to declare the aspects analyzed.

In a previous work where we analyzed students’ ideas about secondary education and future teachers of natural sciences, we found that this type of assessment did not favored a substantial change in their way of knowing (Bravo, Pesa y Pozo 2010). In accordance with this, and as stated before, several research works show that despite instruction, students tend to explain phenomena in intuitive terms incoherent with science. Trying to change this situation and foster significant learning of sciences, we have designed a teaching proposal implemented in a group of 13 and 14-year-old students of secondary education. The methodology employed was characterized by:

- The use of an interdisciplinary and gradual aspect of the model of school science previously described (related with category IV, Table 1). In order to help students overcome the ontological, epistemological and conceptual “gap” separating their initial knowledge from a nearer way of knowing science, the model was gradually tackled. The study of vision started with the analysis of simple and daily situations allowing students to explicitly recognize the importance of light, objects and eyes to see. Then, the study of “dual” interactions among them (light – object and light – visual system) was proposed, to finally wholly deal with them. Since color is considered as a process of visual perception, its study is dealt with after analysis of the vision model. Again, first the variables the phenomenon depends on are analyzed (light, object, visual system) and then the interactions light – object (absorption, transmission and selective reflection phenomena) and light – visual system (perception) are studied. Finally, such interactions are integrated in a unique and systemic model which allows explaining how we see and why we perceive objects of different colors.

- Activities enabling the beginning of the teaching learning process with students’ previous ideas. The aim was to make students put forward explicitly their conceptions along with their characteristics and nature.

- The gradual incorporation of the study of phenomena of increasing complexity that allow students recognize the existence of multiple variables the process of vision and color perception depend on and study the processes of interaction among them.
The incorporation towards the end of problematic situations leading to consider all variables and interactions. The aim here was to help students integrate the different variables and processes studied in a unique and systemic model: that of school science.

The proposal of an interrelated and recurrent teaching of contents making students interpret the phenomena of vision and color perception in daily situations by using models, ways of doing and acting more coherent with science's proposals.

In tandem with the deepening of the proposed contents, special attention was given to metacognitive processes, encouraging students to:

- Recognize scientific knowledge as an alternative way of knowing, but potentially useful to explain several situations; and learn to argue it consistently and coherently. The importance of this instance lies in the assumption that learning does not imply the substitution of conceptions in so far as previous ideas will coexist in the student's mind with the ones built after instruction. The teaching proposal must then help the student learn how to consciously manage the way of knowing according to the context of the demands faced.

- Be conscious and reflect critically upon the learning process experienced along instruction and about what learning science implies. This is a key moment to help students develop critical attitudes about their learning process, recognizing what they learnt and how they did in order to clarify those tools they will keep on using.

The activities designed for this teaching proposal were diverse, including for example both pen and paper and experimental activities; teaching exposition interacting with the group through experimental activities or the resolution of problematic situations. They involved both students and teachers as well as individual and group tasks. They were performed in four phases described in Table 3.

Table 3: Sequence of activities.

<table>
<thead>
<tr>
<th>Instance</th>
<th>Strategies-didactic objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>To motivate (interest) the student through the content from the presentation of different problems. To motivate the student to explain his own ideas. To clarify and exchange previous ideas, showing validity limits and limitations.</td>
</tr>
<tr>
<td>Information</td>
<td>To explain the variables, relations and interactions among concepts when presenting the models of vision and perception of color. To present in an integral and related way the models proposed from school science. To analyse the potential of science ideas in order to solve and respond to the problems presented. To encourage students to engage actively and set out his difficulties and doubts. To foster the presentations of explanations to solve several situations, making use of the ideas constructed. To teach explicitly characteristic procedures of scientific work. To explicitly point at the nature and construction of scientific knowledge and perspectivism of ideas.</td>
</tr>
<tr>
<td>Application</td>
<td>To guide students in employing new ideas in different situations. To encourage students to aveluate their ideas, develop them apply them in order to explain phenomena under study.</td>
</tr>
<tr>
<td>Summary and Conclusions</td>
<td>To summarize and evaluate the change of ideas. To evaluate the potential of the new ideas. To raise conscious and critical reflection concerning the learning process undergone throughout instruction and what learning sciences imply. To set out new open questions that motivate students to continue learning.</td>
</tr>
</tbody>
</table>

The implementation of the proposal involved a teacher whose main function was to guide and guide the learning process, being responsible of the presentation of ideas about school science, the awakening of interest and curiosity in students, helping them to make their ideas explicit, encouraging them to be conscious of their thoughts and to develop, argue, contrast and apply them in daily situations (details about teachers' role, see Bravo, Eguren y Rocha, 2009)
**Objectives**

- To characterize (before and after teaching) the knowledge students under this proposal have about the process of color perception. Such characterization involves the study of an explicative shared model, which requires the acknowledgment of variables and interactions the students consider when explaining the topic under discussion.

- To evaluate (quantitatively and qualitatively) the learning experienced in students as regards vision of color resulting from the didactic intervention and taking as indicative of the process the changes expressed as for the explicative model the students use before and after instruction.

- To interpret the knowledge students before and after instruction and learning experienced in terms of the ontological, epistemological and conceptual principles and ways of reasoning underlying the ways of knowing.

- To analyze and evaluate statistically the differences between the results obtained by the experimental group and the control group.

**Research problems**

- Before the application of the present didactic proposal: do students share characteristic conceptions of an intuitive way of knowing in relation to the process of color perception? Do they use models lacking or using incorrect interrelated variables that allow the interpretation of phenomena from a perspective coherent with science?

- After the development of the didactic proposal, do students present conceptions about color perception coherent with school science? Do the models used to interpret color have a systemic nature, which implies recognizing the multiple variables and their interactions?

- Are there any statistically significant changes (between the initial and final phases) with respect to the use of ideas increasingly coherent with science?

- Are there any significant effects of instruction after some time?

- Are there statistically significant differences when finishing instruction and after some time, between both groups in relation to the models employed by each?

- Are there statistically significant differences between both groups in relation to the changes observed in their ways of knowing?

**Method**

A factorial intergroup design is chosen of two non-random groups (N=32 experimental group and N=35 control group) with pretest – posttest - posttest delay, with quasi control group. The influence and interrelation of independent variables (Instruction time: pre, post and delay; teaching proposal: innovative and traditional; and response category: as described in Table 2) are studied over the dependent variable represented by the probability with which the groups employ different conceptions (underlying categories as described in Table 2).

**Participants**

The research is carried out with two complete groups of students between the ages of 13 and 14, from educational institutions of the city of Olavarría, (Argentina). One of the groups, consisting of 32 students becomes the experimental group, whereas the other of 35 students becomes the control group. Results section, these two groups were required to be conceptually homogenous before instruction.

In order to guarantee the professional homogeneity of teachers in charge of the groups, they had to be University Teachers of Physics and Chemistry, having obtained their degree in the last ten years in the same institution and sharing the same curriculum and, thus, a common didactic formation.
Both teaching proposals (the specially designed and the traditional ones) were implemented in the Area of Natural Sciences. The implementation involved approximately 32 hours, when students developed nine activities and the teacher intervened seven times. The proposal implemented in the control group took approximately 20 hours (the time usually given to the teacher) when five activities were developed.

As this proposal was implemented, periodical meetings with the teacher in charge were held during which not only the ideas students used, but also the teacher’s performance were analyzed. Those aspects which helped students positively in the interpretation of the proposed models were evidenced, as well as those that should be reintroduced, deepened and/or corrected. The control group teacher implemented the proposal usually employed to teach vision without intervention of researchers.

**Intruments**

We employed Multiple Choice Tests that allow evaluating the sort of idea students use when they must choose their explanations. Eight problems set out involve daily and known situations for students. All of them present four options underlying the four categories described in Table 2. Some of the problems set out implied direct responses: how and why do we see objects of certain colors? The other tasks present this phenomenon contextualized in different daily situations, with the aim of knowing whether students are able of choosing their ideas before questions requiring their declaration, as well as whether they are able to choose the same knowledge in different contexts.

**Analysis criteria and procedures**

In order to characterize the ideas in each group of students, the data are treated analogously to Gomez Crespo (2005) (see also Gómez Crespo y Pozo; 2004; Pozo, Gómez Crespo y Sanz 1999). A mean scoring was given to each person in relation to the probable use of different conceptions underlying the response categories. According to the data obtained in each group and time of instruction, the ANOVA test was used in a factorial design 2 x 3 x 4 (two teaching proposals, three times of analysis and four response categories). From this, the influence different independent variables have upon the probability with which diverse conceptions are used is studied (underlying the four categories previously defined).

ANOVA is complemented with the test post hoc (Duncan comparative test), which allows knowing where the differences lie according to the variance analysis in each interaction performed.

**Data and Findings**

Figure 1 shows the probability with which students of both groups use different conceptions before teaching:

![Probability of the Experimental Group and Control Group when using different conceptions en the pretest instance](image)

**Figure 1.** Probability of the Experimental Group and Control Group when using different conceptions en the pretest instance.
The statistical analysis of the data shows that the interaction teaching proposal x category is statistically significant ($F(268;3)=8.62; p<0.0001$), which implies that the groups use the diverse conceptions differently. The post hoc test reveals that the control group employs statistically lower ($p<0.05$) ideas of intuitive nature (underlying categories I and II) than the experimental group. At the same time, ideas coherent with school science (categories III and IV) are used statistically higher ($p<0.05$). The starting point of the students in the control group is more “favorable” as they used more complex ideas, whereas intuitive conceptions are less used.

However, when studying the influence of the variable category (which is significant in both cases: $F(116;3)=38.96; p<0.0001$ for the experimental group and $F(152;3)=15.55, p<0.0001$ for control). The post hoc test reveals that both groups employ ideas underlying category I with a statistically higher probability than the rest ($p<0.01$). Thus, we consider that students share initially the same way of knowing (groups are conceptually homogeneous).

We studied, therefore, the changes the different teaching methodologies encourage about this way of knowing initially shared by students. In Figures 2 and 3, the results obtained are shown in relation with the way the probability was changing as regards their use of different conceptions throughout time.

![Figure 2](image1.png)

**Figure 2.** Change observed in the Experimental Group, with respect to the probability when using different conceptions throughout time.

![Figure 3](image2.png)

**Figure 3.** Change observed in the Control Group, with respect to the probability when using different conceptions throughout time.

Data analysis show that the interaction teaching proposal x time x category is statistically significant ($F(768;6)=25.23; p<0.0001$), which implies that there are differences in how groups employ different
conceptions at different times. In turn, the interaction time x category is significant in each group ($F(364;6)=46.36; p<0.001$ and $F(404;6)=4.02, p<0.006$ for the experimental and control groups, respectively. This means that both the innovative and traditional teaching proposals (and the passing of time) have encouraged significant changes in the probability with which different conceptions are used when explaining the phenomenon of color perception.

The post hoc test shows that within the experimental group, the probability of using basically intuitive ideas (category I) decrease significantly ($p<0.01$) from beginning to end. Then, this probability, which is indeed very low (means 0.1) continues in this way throughout time (i.e. it does not change significantly between posttest and delay instances). The probability with which they choose the underlying ideas to category II decreases significantly ($p<0.01$) as a result of instruction. However, the passing of time also boosts a significant increase ($p<0.01$) in the probability with which students choose, although the delay instance in very low (means 0.1). The probability with which underlying ideas to category III are chosen increases significantly ($p<0.01$) after instruction and decreases significantly ($p<0.01$) between the posttest and delay instances. Finally, the probability with which students use school science ideas (underlying category IV) increases significantly ($p<0.01$) with instruction and no statistically significant differences are found between posttest and delay instances (the probability of students using this conception, which is high indeed, remains invariable with the passing of time).

In the control group, it is observed that between the pre and posttest instances the only difference lies in that the probability of using ideas underlying category IV decreases significantly ($p<0.05$) after teaching. The passing of time does not cause statistically significant changes in relation to the probability with which ideas underlying different categories of response are employed.

Since the way of knowing that the groups shared before instruction is analogous and the different teaching methodologies (as well as the passing of time) encouraged such different changes, it is expected that students end up explaining differently the process of color perception. In this sense, the interaction teaching proposal x category for the instances posttest and delay are statistically significant ($F(264;3)=41.37; p<0.0001$ and $F(263;3)=19.92; p<0.0001$, respectively. Consequently, the differences in the way groups explain phenomena after instruction becomes significant. Figures 4 and 5 show these differences clearly.

![Figure 4. Probability of both the Experimental and the Control Groups when using the different conceptions in order to explain color in the posttest instance.](image-url)
Figure 5. Probability of both the Experimental and the Control groups when using the different conceptions in order to explain color, in the instance delay.

The pos hoc test results reveal that both for the posttest instance and delay, the experimental group employs scientific ideas (category IV) with a statistically higher probability than the control group ($p<0.01$). The idea involved in category III is also used by the experimental group with higher probability both in the posttest instance ($p<0.01$) and the delay ($p<0.05$). The probability with which intuitive ideas are used (categories I and II) in both instances is significantly higher in the control group ($p<0.01$) than in the experimental one.

When carrying out the intragroup analysis, it is found that the variable category causes a significant effect in the experimental group for the posttest instance ($F(124;3)=65.69; p<0.0001$). The most significant fact revealed by the post hoc test is that after teaching, students from this group employ ideas coherent with school science (underlying categories III and IV) with a statistically higher probability than the intuitive conceptions ($p<0.01$). However, no significant differences are found here in the probability with which ideas are used under categories III and IV. No tendency is recorded as regards the tendency of using the idea of school science over the rest. Carrying out a global analysis of the situation, we found that 85% of the responses are grouped between categories III and IV. Therefore, students would end up sharing a way of knowing more coherent with school science than with intuitive knowledge.

During the delay instance, the variable category influences again significantly on the experimental group ($F(124;3)=23.61; p<0.0001$, showing that students eventually choose school science ideas ($p<0.05$).

The control group, during the posttest instance, employs antagonist models with similar probabilities (the significance of the influence of the variable category shows a limit value: $F(112;3)=2.68; p<0.05$). The pos hoc test results show that explanations underlying categories I, II and II are chosen with the same probability. The only idea that is employed with a statistically different probability in relation to the rest ($p<0.05$) is the school science, but it is differentiated as it is the least used.

In the delay instance, the variable category does present a significant effect on the control group ($F(112;3)=5.69; p<0.0012$). The post hoc test results show that, even if basically intuitive ideas are used more often, this is only significantly different ($p<0.05$) from the probability with which conceptions underlying category III are used. But such ideas are used with the same probability (without statistically significant differences) as intuitive ideas (category II) and science school ideas (category IV). The non coherent use of models is expressed in this instance, being the inconsistency the main feature of the way of knowing shared by students from the control group after teaching. Nevertheless, both during the posttest and the delay instances, most responses to explain the perceptive phenomenon (58% at both times), categories I and II were grouped. Thus, a way of intuitive knowledge would be highly shared, based on common sense and daily experience.
Discussion and Conclusions

The results obtained in the pretest phase allowed us to see that before implementing the teaching processes, students in both groups tended to explain the process of color perception from their intuitive ideas. In this sense, they activated ways of reasoning we have characterized as reductionist and monovaried, rather than systemic. Hence, from their daily knowledge and sensorial information, students explained for example that “color is a property of objects”. This way of knowing is associated with ontological, conceptual and epistemological principles of state, fact or datum, as well as naïve realism.

The changes encouraged by the teaching methodologies are essentially different and, thus, eventually the ways of knowing are different after formal instruction. The innovative proposal boosted the decrease in the probability with which students use basically intuitive ideas, and fostered the increased of the probability of using categories III and IV. As a result, their underlying conceptions were employed more often. Students eventually explained the perceptual process in terms of abstracts models and ways of reasoning characterized as multivaried.

However, it was observed that during the posttest instance, the conceptions involved in categories III and IV were employed without statistically significant differences. In order to clarify what sort of knowledge students share, it is worth considering the common aspects underlying such categories. The conceptual central nucleus of the shared ideas underlying both categories would imply recognizing that light interacts with objects causing the absorption, reflection and/or selective transmission phenomena. Also it should be recognized that color depends on the characteristics of the light emitted by the object. This means that students would not yet conceive color as a process of visual perception – an idea that implies a great intuitive notion – but as a product of the interactions occurring between light and objects “outside the observer”, in so far as he must only “see” in order to perceive color. Nevertheless, having overcome the notion that color is a property of matter and having recognized that it is the product of the interaction with light is a solid conceptual basis from which students keep on building the idea of school science. As a conclusion, students from the experimental group would be successfully going through the learning of models of school science as there is a substantial change in their basically intuitive way of knowing to another more coherent with science, characterized by ontological and conceptual principles of processes and multiple linear causality in an evident process to overcome the naïve epistemological realism.

In the control group, however, it is observed that antagonic models are chosen with analogous probabilities, being intuitive conceptions the most widely used. That is to say, it is observed a “competence” of daily notions built from common sense and daily experience and ideas coherent with science, built as a product of schooling. Thus, students seem to use some models coherent with science presented in the class, but they cannot use them with higher probability than they use their “original” intuitive notions. All this would be a product of ad hoc reasoning, where scientific conceptions are incorporated as added hypothesis, although the central nucleus of intuitive conceptions are still kept (Salinas de Sandoval & Sandoval, 1996). For this reason, the students’ way of knowing can be characterized by having a high inconsistency with the employment of a particular conception. The results obtained in the delay instance allow us to evaluate the continual use of ideas built in the science class together with the significance of learning experienced by students, as a consequence of the teaching process implemented.

With respect to the students of the experimental group, we observed that after the time elapsed, they choose with a higher probability science ideas (underlying category IV). These are relevant data to conclude that the learning process encouraged would have implied a complete change in these students’ way of knowing.

In the control group, time does not cause important changes and students keep on using antagonic models indistinctly. In this sense, both in the posttest and delay instances, it is observed that students try to use science models proposed in class although they are neither recognized nor chosen. Therefore, intuitive ideas and others arising from schooling are employed with a higher probability. In addition, it is observed that in both instances most students’ responses were grouped in the categories involving intuitive conceptions and reductionist non-systemic models, based in facts or data and states or simple linear causalities. Thus, at all times, they tend to choose mainly responses such as “an object is seen as red because it is painted in that way”.

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Therefore, we can conclude that the innovative teaching proposal favoured a change in the students’ way of knowing, from one initially intuitive to another more coherent with school science. Also, even in the delay instance, students keep on using models built by schooling.

Traditional teaching, however, did not encourage a deep modification of the students’ way of knowing – and thus, conceptual, epistemological and ontological underlying principles – and still base perceptual phenomena upon intuitive conceptions.

The results obtained in this study evidenced that it is possible to encourage Science learning in Secondary Education, regarding this process as a substantial change in the way of knowing. This implies the gradual change from an intuitive knowledge to another more coherent with science.

With the aim of finding the greatest number of indicators to evidence factors leading to such learning, we analysed the influence of other variables about the type of notions employed after instruction (specifically, the influence of the task, content and teaching performance). Also, we studied how the students’ way of knowing changed according to the advance of the teaching process, avoiding reducing this type of work to the study of pre- posttest (some of which have been analysed by Bravo, Eguren y Rocha 2009; Bravo, Pesa y Pozo 2009).

In future works, we will address the integral analysis of the above mentioned aspects, trying to present concrete data to understand more rigorously how students learn sciences and what teaching strategies are more efficient to encourage such process.

References


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Differences Between Social Science Teachers and Physics Teachers about Beliefs of Competences Model in Mexico

mramirez@ipn.mx

Abstract

This paper shows the results of a diagnostic research that evaluates the perception of teaching competencies by physics teachers, in universities and high schools that have experienced curricular change of the mode of competency-based education (EBC). The research was conducted in both physics teachers in high school and college level nationally and compared with the results obtained with social science teachers in the state of Tabasco. The main purpose is to account for the way in which teachers accept, resist or refuse to change their teaching model as a result of the changes experienced by traditional curriculum to competency-based model, whose main features are that the contents are linked to the productive and social sector; subjects are supported with the use of ICT; to students to acquire skills, and attitudes on the use and transfer of knowledge and thus learning to learn. The results from both disciplines teachers show some common aspects, however, there are also important differences in the appreciation from both groups over the success of this model.

Keywords: Competency Model, Physics Learning, Curriculum Design.

Introduction

In recent years education has been incorporated by the competency model to higher education institutions, both in Mexico and internationally. In this sense, we have made efforts to study the specific competency to be developed in different university programs for various instances; an example of this is the studies conducted by the Tuning Project, both in Europe and in Latin America. In particular, the Tuning Latin America project studied, in chapter 4.6, degree programs in physics in 12 countries including Mexico (Beneitone, 2007).

At other levels, we have studied the progress of changes in plans and programs studies from the introduction of the competency model, in the case of physics programs at the secondary level we found interesting experiences in the Spanish educational model (Cañas,2007).

The work around learning physics by this model is not new, in fact there are efforts by the same Tuning Project (University of Deusto, 2008) where they make suggestions for the design and construction of programs based physical competency model. In the case of teacher training, there are also efforts in the area of physics; particularly, the training of teachers at the National Polytechnic Institute of Mexico (IPN) is related to the institutional educational competency model that follows from the 2000 (IPN, 2004) and have implemented training courses specifically aimed to teachers of physics for understanding and implementation of the model in their courses and Olvera & Ramirez,(2012). Yet, despite the efforts mentioned, the perception of physics teachers about the competency model is still bad, starting with a general ignorance of what is the model by itself, and this has been evident in various academic meetings and area meetings of the AAPT, ICPE and WCPE (Ramirez, 2011; Ramirez and Chavez, 2012).

Methodology

The methodology used to carry out the diagnosis and evaluation of teaching skills in higher education institutions which have implemented Tabasco and operate the competency-based educational model (EBC) is a typical descriptive - exploratory mixed cut, which consists of the following phases: The first phase is the review of governing documents and policies for IES on competency model, the first stage allowed to extract relevant and updated information about the contents that may be incorporated in the analysis and evaluation of this phase. A second stage involved the determination of a representative sample of the teachers in charge of operating the competency-based curriculum model. The research population was formed by higher education faculty active until 2009 that serving in public universities and have
implemented the EBC model. Third stage is a questionnaire that was designed to investigate the ways in which the teacher faces his work under the competency model. The design integrates the categories and units of analysis obtained from a review of the documentary. At the fourth stage, there were conducted fieldwork and instruments that were used to obtain the required information in the study. A fifth point is the systematization of information, there were creating databases and hermeneutic units for analysis and theoretical-empirical recruitment. Finally, a diagnosis-evaluation of the situation that teaching skills in the EBC model was made, which in turn, will be contrasted with the model proposed by regulatory agencies, such as, National Association of Universities and Institutions of Higher Education (ANUIES) and the “Secretaria de Educacion Publica” (SEP). Moreover, for physics teachers retake the instrument used for IESs of Tabasco, with the difference that the application was originated online at:


The sample comprises IES teachers across the country and even we received responses from Physics teachers of the Republic of Cuba.

Analysis

Since the late nineties, it begins to take shape in Mexico the idea of unifying the criteria in the curriculum of higher education level. It is in order to homogenize the credits on track to achieve international accreditation of curriculums to ensure academic mobility and the consequent approval in the training of a global citizen.

Tabasco state located in southeastern Mexico, has not been the exception, but there are certain characteristics that make it a relevant sector of study. It is one of the states with higher educational backwardness indicators at all levels, sometimes only surpassed by Oaxaca or Chiapas.

Earlier reports of this research realize the need to take new teaching skills in higher education teachers from the inclusion of the education system to the EBC model.

Widely, IESs in Tabasco have adopted this model since 2003. This implementation translates as mandatory from a recommendation of World Bank linked to financing, which was taken up by the ANUIES and various educational programs accreditation bodies grouped in the State Commission for Higher Education Planning (COEPES) and Committees for the Evaluation of Higher Education (MES).

Empirical evidences suggest that the proposal, resulting in the design, restructure and sometimes unregulated curriculum amendments, among other things, due to the lack of agreement about the concept of competence, which is also reflected in the confusion of the professor meeting the demand of transforming their teaching practice.

Based on a sample obtained from the Division of Social Sciences at the Universidad Juarez Autonoma de Tabasco, which was elaborated with teachers who recently participated in the Commission for the restructuring of the curricula Bachelor of Law, History and Sociology at the EBC model; it identifies the difficulties in obtaining consensus on the particularities of the model.

The 12 teachers who participated in the study pointing out: the inaccuracies and improvisations in adaptation of the curriculum model for competition are due to the absence of effective training of designers and operators; lacking of consensus among planners and disagreements on the model.

Thus, one interviewee shares: **... when we were named as commissionaires, they gave us instructions on how to make the change by stages to EBC model, when one of the commissioners dared to question that the lack of fundamentals and the damage that this incurred to careers as law, history or medicine. They have significantly restricted their subjects for the formation of generic competencies, the authorities’ response was immediate ... the teacher was removed from the grounds’ commission because she’s blocking out the transformation ... there, we understood that we should only obey the instructions and get out as quickly as possible of the request, (4 dsh22/06/10 interview).**

Further participation points: to restructure the models: **... hire people from outside who do not know the university and its contexts, unaware of teachers experience, historically efforts, they get pay big bucks and they come to tell us how they think things should be ... then, they leave and we have to remediate all ...**
for them, they do always a good job and they report what they want to hear ... (interview 06/29/10 7dsh)

Some important signs, in the confrontation between the being and doing of university teachers against the competency-based model (EBC), gain importance as they become focus of the analysis on the phenomenon

Teachers in charge of operating the new model in the DACSyH, most (57%) beyond the age of 50 years, are teachers who joined during the decade of the seventies and eighties as full-time teachers, with the need to address the phenomenon of massification lived in public universities, so their age in college is an average of 25 to 35 years of service. These indicators allow codifying data provided by informants in empirical work:

University teachers face the need to adapt, improvise or refunding their teaching, from EBC model that has been implemented across the board in all divisions of the UJAT. This has led to the emergence hybrid styles of teaching effective or combination between traditional practices and learning-centered practices.

In this sense, the applied instrument to 37 teachers of T / C, which makes up 50% of the total in this professors category assigned the Academic Division Social Sciences and Humanities demonstrates the following:

98% do not believe in the effectiveness of the model change and they reported having experienced at least three curricular changes in the last ten years; with negative results for program arguing more often the following reasons:

They have trimmed their subjects necessary for the curriculum to incorporate general subjects for all divisions.

They have been forced the disappearance of serial subjects so that in the particular case of law students can sign up without knowing “amparo” constitutional law, in history they first see history of the revolution and then they see the history of independence.

Every time graduates are worse, they are less graduates and they have to take a specialty to end with their formation.

90% said, not clear what the competency-based model mean:

Each course instructor says something different.

There are so many types of what should be a competency that we ending confused.

So many names such as skills, abilities and attitudes that do not quite understand, which goes in the programs that I design.

One of the interview responses clearly summarizes the feelings of the majority of respondents ... “I saw that they met with some teachers, they never invited us and suddenly, we are told to do the curriculum now by competencies, and they gave us a form; then when we had questions or concerns, they just told us just fill it and deliver on that date ... what you cannot fill, the commission does, so we did it and I was already approved.

The 89% of full-time teaching staff said not agree to change your learning style by a competency-based model and refers to the following reasons:

On my years of “teaching”, I have filled satisfaction. My students are excellent professionals.

I have been received awards for academic excellence. Why do I need to change if I have been perfecting over the years?

I am bout to retire, I do not care reforms.

These models come and go, and it is the same, I remember the model of descriptive cards, it was the same.

Tics does not interest me, nor understand That’s why I have a secretary who writes on the computer all for me.
youth who come with their doctorates degrees and apply the competency model are rejected by students, students want to hear experiences, to be guided by someone who has lived the profession, at the end, they come back asking us, the most experience teachers, teach the class.

They are U.S. ideas, we have always taught students to be a good lawyer, to solve problems ... now everything is renamed and they want to sell fantasy.

Yet, when asked how to face the new competencies model required to operate the new curricula, 100% response being prepared and comment:

Not required much, solve problems, I’ve always done

I’ve been in all processes of change since 1965 and have always successfully adjusted because the important thing is that students go to work knowing

the only new thing is the computer and these entangled boards that to me, the truth, I don’t care, the time is devoted to discuss specific cases in my area that is one of the most important in the formation.

I have no clear about the new competencies, I think that neither who designed them know them, I heard them discussing about them: They gave an order and them countermanded it and we only changed it to go out faster.

Carry pupils to court, that’s what they need to do and always we have done, this is really a competency.

they should first learn to read and we can not help them in college. What good is put in place a program that the student will understand, discuss and think if they come without the necessary skills?

I continue with my program, the other, I just put it on the list with its theme, as the authorities want.

For physics teachers the results were analyzed by an interdisciplinary group of faculty, i.e., were not the only physics teachers that make the analysis group but also there pedagogues, teachers of humanities and mathematics teachers among others. The condensed results and the created indexes are shown below:

Questionnaire responses are diverse and cover a wide range of possible answers, which can be classified positive and negative, which is seen in the following Table:
## Tables with answers to the questions their experience in the knowledge of competencies

<table>
<thead>
<tr>
<th>Frequent replies</th>
<th>unique responses</th>
<th>Positive response</th>
<th>Negative response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very little-Little 10 Courses, Dip. Esp 4 No difference I already know it. Investigate on by my own Time in years 1.3, 3, 12</td>
<td>No Bad Hard Good Design UA Lack of understanding concept Lack of Institutional support Lack of curriculum I don’t know.</td>
<td>12</td>
<td>23</td>
</tr>
</tbody>
</table>

### In his opinion: What is the competencies based model?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>unique responses</th>
<th>Positive response</th>
<th>Negative response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrator Model 20 t’s the same 4 It is not clear 4. Develop C with capacities 3 Troubleshooting problems 2 A active student 2</td>
<td>No rejection Achieve goals not know it nonsense</td>
<td>29</td>
<td>10</td>
</tr>
</tbody>
</table>

### Consider that this model is more suitable for the institution? Why?

<table>
<thead>
<tr>
<th>Frequently answers</th>
<th>Unique responses</th>
<th>Positive response</th>
<th>Negative response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes 25 - It is integral - It motivates students-teachers - It makes research arises NO 7 is obsolete - let research and entrepreneurial behind. Only activities are measured It is better solve problems</td>
<td>I do not see the difference I don’t know It is early</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>
What has been your experience in adaptation curriculum to model C?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique responses</th>
<th>Positive R</th>
<th>Negative R</th>
</tr>
</thead>
<tbody>
<tr>
<td>None yet 12</td>
<td>Rejects Student 1</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Design 5</td>
<td>It is easy1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult, change in Ens. 5</td>
<td>No 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lac of information 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st place, the student 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The application is a slow process 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A few 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is good 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is confusing 2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>It is incompetent 2</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

What is the work of university teachers versus model C?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique responses</th>
<th>Positive R</th>
<th>Negative R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mentoring 10</td>
<td>No apply.</td>
<td>31</td>
<td>7</td>
</tr>
<tr>
<td>Upgrading 7</td>
<td>Develop strategies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Be aware and collaborate 5</td>
<td>Develop of Math Laboratory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I don’t know 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation and Realism 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apply and adaptation 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educate and Integral Development 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Do you believe in the effectiveness of the model change and why?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique Replies</th>
<th>Positive R</th>
<th>Negative R</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>Homogenizes 1</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Entrepreneur Student 4</td>
<td>will be slow 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction of needs 3</td>
<td>It is better upgrade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is commitment 2</td>
<td>curriculum 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integral student 2</td>
<td>Lack of agreement 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is already on place 2</td>
<td>It is an opportunity to restructure 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>not</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is better in Basic and MS 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It will be tested first 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of information 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lack of comprehension 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is a lot of work for the instructor 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Opinion: Trend of institutions to change to competency-based model.

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique Answers</th>
<th>Positive R</th>
<th>Negative R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good 5</td>
<td>It is a setback</td>
<td>13</td>
<td>23</td>
</tr>
<tr>
<td>Fad 4 Do not know 4</td>
<td>It limits development and innovation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very bad 4</td>
<td>It creates opposition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3Inertia necessary</td>
<td>It only changes the assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of commitment 3</td>
<td>It was developed by research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>international 2 Mandate soon starts 2</td>
<td>Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>must start Basic Level 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### How do you face the new teaching skills required to operate the new curriculum?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique Answers</th>
<th>Positive R</th>
<th>Negative R</th>
</tr>
</thead>
<tbody>
<tr>
<td>With continuous learning</td>
<td>Calmly</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>It haven’t been applied</td>
<td>Difficult by the number of and students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No 5</td>
<td>Individualized teaching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I don’t know 3</td>
<td>Without institutional commitment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>there is not time 2</td>
<td>Without qualified personnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With two</td>
<td>With educational research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open-mind 2</td>
<td>Changing class and evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bad 2</td>
<td>Not applicable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### What are the strengths of the competency-based educational model?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique Answers</th>
<th>Positive R</th>
<th>Negative R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targets and skills that it develops</td>
<td>It is for beginners</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>active Student</td>
<td>There is not difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changing mindsets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I don’t know 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I don’t identify it</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generic evaluation and skills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Realism and usage of TIC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitudes and values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personalized teaching</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What are the weaknesses of competency-based education model?

<table>
<thead>
<tr>
<th>Frequently Answers</th>
<th>Unique Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>I don’t know 6</td>
<td>There is not difference</td>
</tr>
<tr>
<td>Resistance to change 5</td>
<td>Need of good teachers</td>
</tr>
<tr>
<td>I don’t not know 5</td>
<td>Lack of time</td>
</tr>
<tr>
<td>Lack of communication between Education’s actors 3</td>
<td>It is receding, In some countries, it have failed</td>
</tr>
<tr>
<td>Teachers do not understand 3</td>
<td>It is not covered Educate Plans</td>
</tr>
<tr>
<td>All 2</td>
<td>Teachers</td>
</tr>
<tr>
<td>It is imposed. 2</td>
<td>No study of Science</td>
</tr>
<tr>
<td>It is not necessary in ES 2</td>
<td>Ambiguous Definition</td>
</tr>
<tr>
<td>Language not clear 2</td>
<td>Number of Students</td>
</tr>
<tr>
<td>It does not say how to develop skills and evaluate 2</td>
<td></td>
</tr>
</tbody>
</table>

What is observed in response tables is that two thirds do not have experience in the learning model (1), the model itself is quite accepted (2) but not as a trend (7).

It is good, right (3), some curricula have already been restructured (4), It is considered very positive for Teachers (5).

There are some doubt that the change is effective (6), but it is considered to be a good adaptation effort (8).

The model has many strengths and weaknesses that are implemented by itself.

Conclusions

The presented project progress allows us to draw some preliminary conclusions:

Based on the review of available literature on EBC model it can be said that there is not a theoretical-methodological proposition for its definition and the existing have not reached a consensus in our country, which largely explains the disagreements of the design and operation of the educational curricula of IES which have moved into this mode.

EBC model is a proposal that emerges labor market, from there, it is defined competencies that become teaching goals. This new dynamic means that the University must have an active and effective role in promoting closer ties with production structures, which it is not easy because the different motivations and objectives that constitute their agendas. Cuban (1992) argues that the difference between the two bodies is mediated by a cultural problem and explains it in relation to what they feel like a threat:

... the culture of the university is to value reflection, analysis, scientific research, while the company evaluates the application of knowledge to practical situations and experiences based on knowledge that is applicable to their processes.

Curriculum design EBC model is done by “order” because it’s pointing to the formation of professional “mode” doomed to meet the human capital requirements of companies and employers.

EBC model requires specific competencies for its operation. But teachers who are responsible for its operation, coming from rigid structures, highly professionalizing teachers that understand teaching as an subjective, individual and personal exercise that depends of the experience for its completion.
University teachers have responded to the requirements model with attitudes of resistance, considering the effectiveness of their practices, or denying their involvement in it, by a by open refusal to its participation; others have adapted to the new conditions with a positive attitude, open to change. However, the study begins to outline that teachers with more seniority and teaching experience reject or resist change for reasons to discredit and lack of agreement with the model.

When the EBC model is focusing on performance, it rejects aspects like teaching experience and the tacit knowledge that the professional requires. It is clear that teachers have made interesting proposals in reflective practice, known as Schon (1998) in his book The Reflective Professional: how professionals think when they act, hence the importance of recovering the way to deal with change to suggest models for IES teachers in Mexico.

Physics teachers seem to be more open, but are polarized on their view of the competency model. An interesting situation is that although many comments on the model many of them indicate a lack of knowledge about the model.

An interesting situation is that teachers whose knowledge of the EBC model is better manifested their inability to give a diagnosis of the model at this time, based on the thought that they need to see several generations of students to assess the success or failure.

References


Imbernon (1994). La formación y el desarrollo Profesional del profesorado, hacia una nueva cultura profesional. Barcelona: Grao


WCPE 2012, Istanbul, Turkey
Scientific Modeling Seen as a Conceptual Field: Theoretical Approach and Preliminary Empirical Evidences of Possible Operational Invariants on the Learning of Physics

Rafael Vasques Brandão, Application School, UFRGS, Porto Alegre, RS, Brazil
Ives Solano Araujo, Institute of Physics, UFRGS, Porto Alegre, RS, Brazil
Eliane Angela Veit, Institute of Physics, UFRGS, Porto Alegre, RS, Brazil

Abstract

The present work supports the idea that the scientific modeling process in physics can be seen as a conceptual field underlying the domain of specific conceptual fields of that science. This topic is especially important to design teaching units focused on physic's conceptual understanding through modeling activities. This idea is based on two theoretical approaches: Vergnaud’s conceptual fields theory, of didactic and cognitive developmental nature, and Bunge’s epistemological viewpoint concerning scientific modeling process. Starting from these approaches, we constructed a Conceptual Structure of Reference (CSR) which stipulates the concepts and their relationship associated with the notion of model and the process of scientific modeling - together with the patterns of thought that organize the individual acts in modeling situations. This CSR makes up the conceptual field of scientific modeling in physics, with didactic purposes. An exploratory case study was designed to gather empirical evidence of the relevance of this CSR to modeling physical-situations, as well as to look for operational invariants. The case chosen is a bright young high school physics teacher who is also a student in a graduate program of physics education. She attended a 16 weeks course focused on computational modeling activities, and her experiences in this course constitute the focus of our qualitative analysis. Based on interviews, the observations of her actions during the processes of modeling some specific physics-situations, and her explanations for the colleagues, we got empirical evidences for two operational invariants she used on the process of conceptualization of real-physical situations especially in computer didactic-scientific modeling task. These findings corroborate the potentiality of the theoretical framework presented here to better understand the construction of knowledge associated with the scientific modeling process. This understanding is vital to develop a meaningful learning of physics combined with a good comprehension of the main role of models in science.

Introduction

Scientific modeling – understood as the process to construct, validate, use and correct scientific models – underlies modern science, but only in recent decades there has been efforts focused on developing theoretical frameworks and didactical strategies to support modeling activities in physics education (Windshitl, Thompson & Braaten, 2008; Hestenes, 2011; Uhden at al., 2011; Araujo, Veit & Moreira, 2012).

On the other hand, there is a broad consensus of the importance of teaching strategies that emphasize a critical reflection of the content addressed by both students and teachers of high school. Several researchers (e.g. Bliss at al., 1994; Wells, Hestenes & Swackhamer, 1995; Justi & Gilbert, 2002; Giere, Bickle & Mauldin, 2006) believe this could be achieved with a strategy based on modeling.

Considering the contribution of an adequate understanding of scientific modeling can give to the teaching practice and student learning in high school, this research aimed to investigate predicative and operative forms of knowledge about scientific modeling by high school physics teachers.

We adopt the following starting premises:

- the main purposes for science education is learning of science, learning how to do science and learning about science, as stated by Hodson (1992);
- this requires to address models and modeling, as suggested by Justi & Gilbert (2002, p. 370):
First, ‘learning of science’ implies that students should come to know the natures, scope and limitations, of major models that are products of science. Second, ‘learning how to do science’ implies that students ought to create and test their own models. Third ‘learning about science’ implies that students come to appreciate the role of models in accreditation and dissemination of the products of science enquire;

- scientific modeling process permeates the whole physics and the conceptual elements necessary for domain this process play a key role in scientific explanations and practices.

As a consequence, it is reasonable to expect that explanations of high school teachers and students should involve concepts associated with models and scientific modeling in physics, as well as their patterns of thought should contain operational invariants to deal with situations that give meaning to the fundamental concepts involved in modeling physical situations.

Trying to shed some light in this topic, we conducted a preliminary study to identify conceptions and difficulties of some high school Brazilian teachers working on physical situations presented as tasks focusing on conceptual aspects of scientific modeling (Brandão, Araujo & Veit, 2008; 2010). In another study, we constructed two alternative and equivalent forms of a questionnaire with 23 statements each, to be used as an auxiliary tool for the evaluation of teaching strategies based on theoretical and methodological elements of scientific modeling process intertwined with scientific content (Brandão, Araujo, Veit & Silveira, 2011).

But there were several questions to be answered yet. For instance: What are the fundamentals concepts associated with models and scientific modeling in physics? What are the operational invariants (concepts-in-action and theorem-in-action) necessary to deal with situations that give meaning to the fundamental concepts involved in modeling physical situations? Which operational invariants a high school teacher uses to solve some modeling physics tasks?

To answer the first two questions, a theoretical study has been conducted starting from the Theory of Conceptual Fields by Gérard Vergnaud (1993), and Mario Bunge’s epistemological perspective for scientific models and modeling (1974). While in the former the core of cognitive development is the conceptualization, in the latter model is a key concept to understanding the modern scientific activity. To answer the third question an exploratory case study, within the meaning of Yin (2005), was conducted. Here we show the mains results of both these studies.

**Method**

The research methodology adopted includes a theoretical and an empirical case study. In the theoretical study we construct a Conceptual Structure of Reference (CSR) associated to the notions of models and scientific modeling in physics, starting with Vergnaud’s and Bunge’s theoretical frameworks. The empirical study consists of an exploratory case study, within the meaning of Yin (2005). A CSR is defined as “a set of concepts, relationships between them, principles, knowledge claims and explanations regarding certain conceptual field, as it appears formulated, explained and is consensual in discussions and in specialized texts of a certain scientific community of reference” (Otero, 2006, p. 47)

**Theoretical study**

We choose Vergnaud’s Theory of Conceptual Fields (TCF) because it has been a fruitful theory to establish “better connections between the operational form of knowledge, which consists in action in the physical and social world, and the predicative form of knowledge, which consists in the linguistic and symbolic expressions of this knowledge”. (Vergnaud, 2009, p.83).

To help students to learn science, how to do science and about science, we are interested on the connections between the epistemology of physics and a better understanding of the conceptualization process of physical situations by the students; unlike the usual investigation on learning of physics based on the conceptual fields theory, we are not interested on a specific field of physics but rather on general knowledge (operational and predicative) associated to the modeling processes that underlies all specifics conceptual fields of physics. But what is a conceptual field?

According to Vergnaud (1990) a concept is formed by a triplet $(S, I, R)$ where:

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- $S$ is a set of situations that give meaning to the concept in a variety of ways;
- $I$ is a set of operational invariants (properties, relations, objects, theorems-in-action, etc.) that are increasingly understood by the subject;
- $R$ is the linguistic and symbolic representations of these invariant which are used to indicate them, to communicate them, to discuss them and, therefore, to represent situations and procedures.

Concepts and situations are tied together as the keystones of conceptual fields, which are informal and heterogeneous set of situations, problems, concepts, relations, structures contents and operations thought. For instance, some specific fields of physics as mechanics, thermodynamics and electromagnetism constitute conceptual fields. The cognitive development occurs through conceptual fields, more specifically on the progressive schema the subject develop to deal with a variety of situations inside a conceptual field.

Some others important concepts and definitions of the TCF are:

- **schema** defined as “An invariant organization of behavior for a certain class of situations” (Vergnaud, 1998, p. 229), where the organization consist of: goals, sub-goals and expectation; rules of actions, operational invariants (concepts-in-actions and theorems-in-action) and possibilities of inference;
- **concepts-in-action** defined as objects or predicates assumed as relevant by the subject;
- **operational invariants** mainly consisted by concepts-in-action (to categorize and select information), and theorems-in-action (to infer, from the available and relevant information, appropriate goals and rules)” (Vergnaud, 1997, p.229);
- **Theorems-in-action** defined as “propositions held to be true by the subject when he or she acts” (ibid, p. 229);
- **conceptions** are “composed of objects, properties, relationships, transformations and processes. There are objects at quite different levels: ordinary physical objects, sets, numbers, functions, graphs, groups, deferential equations, etc.”(ibid, p. 230)
- **competences** “are composed of scheme aimed at facing situations: they are not made of texts. Schema are the operational side of knowledge” (ibid, p. 230).

We are particularly interested on the conceptions and competences needed to modeling physical situations by the subject that are being introduced to this conceptual field.

For Bunge (1974) scientists theorize about the nature, in last instance, with the goal of apprehending reality by thought. Some of his philosophical conviction about the “reality” could be resumed as: i) there are things in themselves, that is, objects whose existence do not depends on human mind; ii) things in themselves are knowable, although via partial and successive approximations rather than exhaustively and at once; iii) the description of natural objects and facts is achieved together by theory and by experiment (iv) the factual knowledge is hypothetical more than apodictic therefore is correctable and not final, although the philosophical assumption that there are things out there, and capable of be known, constitutes presuppositions of scientific research, any scientific hypotheses is correctable, and (v) knowledge of a thing in itself, far from being straightforward and pictorial, is surrounding and symbolic.

The keystone in the process of conceptualizing physical situations is the concept of models, having it two main meanings: i) the model as a schematic representation of an (concrete) object or event in the physical world, named object-model; and ii) as a specific theory (theoretical model) of this idealization. The conceptual reconstruction of the physical world begins with the search of an answer for some specific questions about referents of this world. The kind of question defines the general physical theory to be used, but its application does not occur directly on the referents of the physical world, but rather on elements (objects or events) of an idealized world. The most important concept associated with the process of creation of this idealized world is idealization, that is, given a physical system, decide which referents and key features should be represented and how can it be represented.

---

1 Referent means objects and real events (or assumed as such) that make up the physical system and its neighborhood, and that will be the subject of representation.
2 In case of inexistence of a general theory, some partial hypothetical deductive set of theoretical propositions.
Another important decision is to choose variables/parameters to represent referents’ properties, and which of them assume continuous or discrete values. Bunge highlights that it is important to distinguish the physical world, with all its complexity, from the idealized world and the model that represents the physical system in this idealized world. In the processes of describing physical situations hypotheses are formulated, and some principles and laws can be applied to the idealized world; thus the theoretical model generates results that can be tested comparing to experimental data or looking for internal logical consistency as well as consistency with the knowledge produced by the whole scientific community. In other words, the model should be validated and a domain of validity is established. Frequently it is useful (or even necessary) to do approximations, that is, some mathematical simplifications, such as neglect effects that are small, considering only linear relationships, discard noise, etc. How adequate a model represents the physical situations depends on the desired degree of precision. In order to obtain more accurate results and/or best to interpret them, often new references, variables, parameters, relationships and/or physical concepts are included, that is, an expansion of the models is proposed. Finally, the possibility of a model generalization (conceptual/mathematical) can be evaluated in terms of its utility to represent other physical system than the one for which it was primarily designed.

**Empirical study**

Attempting to obtain some preliminary evidences about operational invariants applied in modeling activities by physics teachers, we conducted a case study. The case chosen was a young physics teacher who was also a student in a graduate program of physics education. Rachel (fictional name) was chosen because she was the brighter student of the three classes we worked with, one per year, along three years; and she had very high grades along the undergraduate and graduate courses. This choice was done in order to control the lack of conceptual physics understanding as an explanation for possible difficulties in the modeling activities proposed. She attended a graduate course focused on computational modeling activities, and her experiences in this course constitute the focus of our analysis. There were seven students enrolled in this course, all of them high school physics teachers. Rachel was one of the three women. There was one meeting per week, lasting 4 hours each, during sixteen weeks. Classes were taught through theoretical and practical lessons. The theoretical approach included lectures, readings of class notes, articles and discussion of them. The practical activities relate especially to the exploration and/or creation of computational simulations involving concepts, models, laws, principles and theories of classical physics. Most of the time, the students had worked on some modeling activity in small groups (2 or 3 students per group).

The main goal of the proposed activities was to present physical problems for the students for which they were already accustomed to seek solutions, but without reflect on it, in the light of scientific modeling; that is, on the concepts shown in Fig. 1. In other words, contemporary epistemological notions were introduced imbricated with the subject content, emphasizing the conceptual elements necessary for understanding the nature of the process of scientific modeling in physics. The performance of each student was evaluated taken into account his/her domain of i) the content of physics, ii) conceptual aspects of scientific modeling involved in the proposed activities, and iv) the use of computational resources as a tool to solve physical problems. The teacher and students made use of Moodle platform\(^3\) to post materials and to work collaboratively even outside the classroom.

**Findings**

**Theoretical results**

The Figure 1 shows the Conceptual Structure of Reference (CSR) we propose to be the basis of the didactic-scientific modeling framework. This CSR brings concepts and relationships associated with scientific models and modeling process. The conceptual field of scientific modeling in physics, with didactic purposes, is made combining this CSR with patterns of thought that organize the individual acts in modeling situations (schemas).

\(^3\) [https://moodle.org](https://moodle.org)
In order to understand the process of scientific modeling in physics it is fundamental that the subject dominate a set of situations and problems that require, in turn, the domain of specific concepts of distinct nature, but inseparable from the notion of model and the process of scientific modeling in physics. Under the light of the TCF, scientific modeling in physics can be seen as a conceptual field consisting of:

- a set $S$ of physical situations that give meaning to the concepts associated to notions of models and scientific modeling in physics;
- a set $I$ of operational invariants i) of general nature associated with the notion of model and the process of scientific modeling in physics, and ii) of special character, associated with the concepts of the CSR, which can be recognized by the subject and used to analyze the situations of the set $S$, called modeling situations in physics;
- a set $R$ of symbolic representations that can be used to indicate these invariants, and therefore represent situations and modeling procedures to deal with them; this set is strongly dependent on specific conceptual field of physics in which the subject is modeling.

Scientific or didactical modeling could be seen as a theoretical-methodological tool to guide actions of the subject in situations where he/she, somehow, needs to model physical situations, that is, to conceptualize the real in the context of physics. In the educational context, it can be denominate as didactic-scientific modeling.

Table 1 shows examples of operational invariants of general character associated to the concepts of model and scientific modeling; and examples of operational invariants of specific character associated to the each concept of the CSR.

The operational invariants in Table 1 are examples of knowledge about scientific models and modeling in physics to be mobilized by the subject in modeling situations. They constitute a conceptual basis, implicit or explicit, which allows the individual to select relevant information, to infer the goal to be achieved and the most appropriate procedures during the modeling process.

**Empirical results**

Here we just quote the results related to the following research question: Which operational invariants Rachel uses to solve some modeling physics tasks?

We found evidences of two possible operational invariants used by her in modeling situations.
The first, associated with the construction of scientific models is to idealize the most as possible the physical situation in study in order to treat it in a most schematic form, regardless of the theoretical perspective under which the situation is being addressed.

The second, concerning the validation of computational models, is never consider the possibility that the simulations were wrong, regardless displaying or not behavior similar to that expected in an actual experiment.

Examples of empirical evidences that led us to identify these operational invariants are presented as follows.

The first modeling activity was performed with pencil and paper. It consisted of formulating a question about two physical scenarios and to propose a scientific model to be used to answer the formulated question. See Table 2.

Rachel proposed the same conceptual model to represent the water in both situations (Table 2, third column), although in the second one the liquid is in equilibrium, and it is not necessary to consider it without viscosity and neither makes sense to conceive it as being irrotational. This example illustrates the use of the first operational invariant quoted above.

In another episode, Rachel had to interact with a simulation about the damped oscillatory motion of a block attached to a horizontal spring and subject to the frictional force with the horizontal surface on which it oscillate (Figure 2).

**Table 1.** Examples of operational invariants.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Operational Invariants of Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model e modeling</td>
<td>To formulate questions about a physical situation to be answered through the construction and/or exploration of a scientific model.</td>
</tr>
<tr>
<td>Model e modeling</td>
<td>To decide what kind of representation to use to answer the formulated question(s).</td>
</tr>
<tr>
<td>Model e modeling</td>
<td>To represent the physical situation schematically under the light of some specific conceptual field of physics.</td>
</tr>
<tr>
<td>Model e modeling</td>
<td>To analyze the reasonableness of results obtained with the version of the scientific model built</td>
</tr>
<tr>
<td>Referent</td>
<td>To delimitate objects and actual events (or assumed as such) that make up the physical system and its neighborhood, and that will be the subject of representation.</td>
</tr>
<tr>
<td>Idealization</td>
<td>Given a physical system, decide which of its key features should be represented.</td>
</tr>
<tr>
<td>Approximation</td>
<td>Given a previously idealized physical system, decide which mathematical simplifications to be assumed, such as neglect effects that are small, considering only linear relationships, discard noise, etc.</td>
</tr>
<tr>
<td>Variable/Parameters</td>
<td>To identify which variables/parameters are needed to represent the physical system, and which of them assume continuous or discrete values.</td>
</tr>
<tr>
<td>Domain of validity</td>
<td>To identify situations in which the theoretical results provided by the model doesn’t match the behavior of the physical system, within a tolerable margin of error.</td>
</tr>
<tr>
<td>Degree of precision</td>
<td>Given an idealization, evaluate qualitatively and/or quantitatively the error introduced by it on the model results compared to experimental or theoretical results.</td>
</tr>
<tr>
<td>Expansion</td>
<td>To include new references, variables, parameters, relationships and physical concepts in order to obtain more accurate results and/or best interpret the model.</td>
</tr>
</tbody>
</table>
**Generalization**

Given a conceptual and/or mathematical model, see if it can be useful to represent other physical systems than which it was designed.

### Table 2. Rachel answers for the first activity, done with pencil and paper.

<table>
<thead>
<tr>
<th>Situation to be problematized</th>
<th>Formulated question</th>
<th>Conceptual model</th>
<th>Theoretical Model</th>
</tr>
</thead>
</table>
| Flow of water inside a pipeline | How does the flowing of a fluid behave at any point of a variable diameter pipe? | The water is incompressible, non-viscous and irrotational. | **Continuity equation** $R = A|\dot{v}|$
  |                      |                      | **Bernoulli:** $\frac{1}{2}pv^2 + p_0 + g\frac{h}{c}$ |
| A water tank completely full. | How does pressure behave at a point at a depth $h$ inside a water tank? | The density of water is constant. Water is incompressible, non-viscous and irrotational. | **Stevin’s Law:** $p = p_0 + gh$ |

**Figure 2.** Screen of a simulation about a damped oscillatory motion. Although the friction is between two solid objects (the block and the surface), the model implemented in software Modellus included a friction proportional to the velocity of the block.

After exploring the simulation, including access to its mathematical model, Rachel had to identify the referents of the simulation as well as the idealizations and approximations assumed. However, the mathematical model contained, purposely, the following error: the force exerted on the block was written as $F = -kx - bv$. That is, the second term on the right represents the force resisting the relative motion of the block and the air, instead of the friction between two solid objects (block and surface).

The referents were identified by Rachel as the spring, the mass, the floor and the wall. Regarding idealizations and approximations assumed in the simulation, Rachel recognized that the spring obeys Hooke’s Law, it has no mass and there is friction between the block and air.

Rachel mentioned the mass as a referent, instead of the body. So, or she was confusing the body with one of its properties (the mass) or it was merely a language misleading. However, after the teacher asked her for some more care with the language, she never more did this mistake along the whole course.

After identifying the referents, idealizations and approximations, Rachel established the following dialogue with the teacher.
Rachel: *We had a lot of discussion about the damped system: Whether it was friction with the floor or friction with the air. Then I came to the conclusion that it was friction with the floor and not the air.*

Rachel was talking about the discussion with the two others elements of her group about what was being considered in the model: solid-solid or solid-fluid friction. At the end of the group discussion she changed her conclusion to the wrong one. The teacher tried to understand why they did not realize that there was an error on the simulation.

Teacher: *But that wasn’t written in the Notes window [of the software]? It is written on the Notes window that it is with the floor. It says: friction between two solid surfaces. So it would be in accordance with your conclusion (...) But I would like to understand why you concluded that?*

Rachel: *I do not remember. But I remember that I did not have this opinion [before group discussion].*

Teacher: *But how is the friction with the floor?*

Rachel: *It is $\mu N$. That’s the reason why I thought there was friction with the air.*

This dialogue illustrates the use of an operational invariant which may be acting as epistemological obstacle to the validation of computer simulations: the assumption that computer models or simulations are correct and do not need to be verified in order to identify possible sources of error and/or limits of validity. Although Rachel had demonstrated knowledge of the mathematical expression used to represent the force of friction with the surface and had access to the mathematical model underlying the simulation, she did not consider the possibility of errors in the simulation and she did not ask the teacher about this. Apparently, if she were modeling with pencil and paper she would represent correctly the friction with the surface as $F_{\text{friction}} = \mu N$, however while using a simulation where this expression did not appear she did not care about this.

Here we presented only one example for each operational invariant, but we had observed Rachel along the whole course and there are several other evidences.

4. Conclusions

As briefly was shown scientific modeling process in physics can be seen as a conceptual field underlying the domain of specific conceptual fields of physics. The Conceptual Structure of Reference associated with the notion of model and the process of scientific modeling has also been shown. The CSR together with the schemas that organize the individual acts in modeling situations make up the conceptual fields of scientific modeling in physics, with didactic purposes. Research findings show evidences for two operational invariants applied by a high school physics teacher facing modeling physics situations. There is a long way to go in this field to really contribute for the teachers practice but the first steps were done.

5. Acknowledgement

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First Steps into Physics in the Winery

Roberto Benedetti and Emilio Mariotti, Department of Physics, University of Siena, Italy
Vera Montalbano, Department of Physics, University of Siena, via Roma 56, 53100 Siena, Italy.

Correspondence concerning this article should be addressed to Vera Montalbano.

Abstract

Physics is introduced as a basic matter in the curricula of professional schools (i.e. schools for agriculture, electronic, electrical or chemistry experts). These students meet physics in the early years of their training and then continue in vocational subjects where many physics’ topics can be useful. Rarely, however, this connection between physics and professional matters is quite explicit. Students often feel physics as boring and useless, i.e. very far from their interests. In this kind of schools it is almost always required the physics lab, but it does not always exist. The physics teachers of a local Agricultural Technical Institute asked us to realize a learning path in laboratory dedicated to their students, since in their school the physics lab was missing. This institute is the only public school in the Chianti area specializing in Viticulture and Enology, and attending a further year post diploma, allows the achievement of the qualification of Enologist. We report a learning path realized starting from thermal equilibrium to a full understanding of the measures made with the Malligand’s ebulliometer. This device is used for determining the alcoholic strength (alcohol concentration by volume) of an alcoholic beverage and water/alcohol solutions in general. The aim was to make interesting measures of physical quantities, calorimetry and state transitions connecting them to the functioning of an instrument that students use in their professional career. We present our considerations on the students’ learning process and on the possibility of extend a similar path. The feedback of students and the interests of their teachers convinced us to go further in this way. We intend in the next future to involve teachers of physics and vocational subjects in the design of a physics curriculum spread over two years in which the main physics topics will be introduced to explain the functioning of tools and equipment used, normally, in the winery.

Keywords: vocational school, motivational strategies, laboratory, calorimetry, change of phase

Physics and technology are closely related. Therefore, in vocational education physics is considered a base for many professional subjects. In Italian professional curricula, physics is planned in early years (2-3 hr/week for one or two years, where many activities are expected in laboratory). Regrettably, current practise is very different from one school to another. Sometimes, laboratory is not properly equipped and usually physics and vocational teachers do not coordinate their educational action. Despite selected physics topics are essential for understanding many professional subjects and practises, the connection almost always remains hidden. In some cases, the relevance of physics to the everyday situation in which the student will ultimately work may not be at all apparent. Thus, students perceive physics as a set of laws very far from their interests, i.e. tedious and useless.

On the other hand, physics teachers often have a professional outlet in vocational schools, especially for those graduates in physics. Thus, they are compelled to work in less favourable conditions with little motivated students.

In the last decades theory and research have been concerned with the relation between motivation and learning (e.g. Alderman, 2008; for a short review focused on physics see Fisher & Horstendahl, 1997). Vocational education enhancement requires to explore and understand how transfer of knowledge can be made more effective in this context (e.g. Guile & Young, 2003; for a discussion on the problem of knowledge in vocational curricula see p. 66).

Moreover, the study of agriculture and related topics can provide a context in which science and mathematics key concepts and skills can be explored in order to enrich students knowledge (Dayley, Conroy, & Shelley-Tolbert, 2001). For these reasons, we developed a learning path in this context for investigate the possibility of improving the motivation of students and teachers and if it can be a way for enhancing learning achievements.
We report a curricular lab designed for the second class (15–16 years) of an Agricultural Technical Institute within the Italian National Plan for Science Degree. These work arose from a request made by physics teachers of the local Agricultural Technical Institute of realizing a learning path in our educational laboratory for their students, since there was no physics lab in their school. The goal was to make interesting measures of physical quantities, calorimetry and state transitions connecting them to the functioning of an instrument that students use in their professional career.

In the next section, we summarize the purpose and the methodological choices of National Plan for Science Degree for explaining the reasons for which this collaboration with the secondary school was made possible and successful. In the following one, we give a description of the school in which we realized the learning path. In order to design an appealing learning path for this kind of students, we found inspiration in the context in which students and teachers usually work. Finally, we describe the learning path in details. Some examples of materials used in class and data from students are reported. In the last section, we discuss the results and give some suggestions for further developments in this school and more in general in vocational education.

National Plan for Science Degree

In recent decades, it has been detected almost everywhere a consistent decrease of graduates in science disciplines, i.e. Mathematics, Physics and Chemistry.

In order to contrast this trend, Italy launched a large and structured plan funded by the Ministry of Education and Scientific Research named National Plan for Science Degree (Piano Lauree Scientifiche, i.e. PLS) in which more than 30 university in all the country realized actions in order to promote scientific degrees through professional development of teachers and orienting of students essentially by means of laboratory activities (PLS website; for a survey of local PLS activities: for Southern Tuscany see Montalbano, 2012, or for Naples and surroundings see Sassi, Chiefari, Lombardi, & Testa, 2012).

The main strategy and methodologies are the following:

- Orienting to Science Degree by means of training,
- Laboratory as a method not as a place,
- Student must become the main character of learning,
- Joint planning by teachers and university.

The main action is centered on PLS laboratories, designed by university and teachers, in which groups of students (up to 15, better if much fewer) perform experiences in physics laboratory. A characteristic of PLS laboratory is that should not be episodic, i.e. students need to be engaged in this activity for a sufficient time (15 hr or more).

According to the national guidelines, PLS laboratories can have different purposes: Laboratories which approach the discipline and develop vocations, Self-assessment laboratories for improving the standard required by graduate courses, Deepening laboratory for motivated and talented students (e.g. Benedetti, Mariotti, Montalbano, & Porri, 2011; Di Renzone, Frati, & Montalbano, 2011).

The activity described in the following can be classified as a laboratory which approach physics and its purpose is to increase the scientific literacy in students who usually have little interest in physics.

A Peculiar School

The Agricultural Technical Institute Ricasoli is one of 10 Italian technical special secondary schools specialized in Viticulture and Enology and the only one in Tuscany. After a course of five years, students become expert in Viticulture and Enology and, with a further annual course, are qualified as winemaker technician (Ricasoli Website).

The school was born in 1952 and occupies an area of 47 hectares (116 acres) and deals with managing the educational farm. The Villa of Partini (Sienese architect 1842-1895) hosts the School’s Management,

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the offices of the Secretariat and the Library of the School from which you can dominate the whole area of Chianti and the city of Siena.

Each last class is responsible for a vineyard and students treat all aspects from the cultivation of the vine to the grape harvest, from fermentation to bottling, oversee and determine what is needed to ensure the quality of the final product.

Every year, the last day of school is devoted to the Enological Day. Parents, students, everyone is invited to taste the products made by students during the year. Wine tasting ends with the awarding of the winner of the best wine produced from the last classes.

Therefore, students live in a context where wine culture is deeply embedded with countryside, local history and economy, social tradition and likely their future profession.

For these reasons, we proposed a learning path centered on the use of a professional device routinely utilized by any enologist: The Malligand ebulliometer or ebullioscope (Malligand, 1876).

**From Thermal Equilibrium to Alcoholic Strength Measurement**

In the following we give elements useful for understanding how we designed the learning path in the way we did. We describe methods, materials, the organization of activities and how we thought to evaluate the effectiveness of this learning path and participants. The next section would be dedicated to analyze data and findings.

**Physics Contents**

**The alcoholic strength measurement.** Wine and each alcoholic beverages obtained by distillation can be regarded as pure water/alcohol solutions from the physical point of view. All the other components, although important from the organoleptic point of view, are present in quantities which are too small for having an influence on the measurement of alcoholic strength. The alcoholic strength can be determined for ebullioscopy, valid for commercial labelling and trade and which uses a special device: Malligand ebulliometer.

The method is based on different temperature of boiling water (100 °C) and ethanol (78.3 °C), which together give a mixture which has a boiling point intermediate between that of the two substances. Wine is a hydro-alcoholic mixture and has a boiling point which decreases with the increase in content in ethanol.

**The Malligand ebulliometer.** The apparatus is showed in Figure 1 and the labeling in the text refers to the schematic drawing on the right. The Malligand ebulliometer comprises a metal boiler $F$ connected beneath to an annular tube which is inclined and welded to a small chimney $S$ beneath which a heating lamp $L$ is positioned. This annular tube makes it possible for the liquid present in the boiler to be heated by thermal siphoning. The boiler is closed with a screwed lid provided with holes and has a metal arm $E$ bent into a right angle. A thermometer $T$ passes through the central hole in the lid and its bulb dips into the boiler while its capillary, which is also bent into a right angle, is housed horizontally in a metal arm, against a graduated scale $c$. A cooling unit $B$, whose function is to cause condensation of the alcoholic vapours to prevent any change in concentration of the solution altering the boiling point, is housed in the side hole of the cover.

**Learning Path Description.**

**Overview.** The measurement of alcoholic strength needs elements of thermal exchanges, properties of matter in function of temperature and changes of state properties. Thus, we decided to design a learning path that started by characterizing thermal equilibrium, gave some elements of calorimetry, analyzed temperature in a system where a constant amount of heat is supplied and finally utilized the Malligand ebullioscope. Despite PLS indications, we had no enough time for joint planning with teachers. They contributed to the timing optimization of labs and lessons, discussed with their students in classroom the concepts introduced and the data obtained but did not participate to initial educational choices.

**Methods.** The learning path was designed as a PLS laboratory realized during school hours. We planned 3 activities in laboratory (each one of 3 hr for a total of 9 hr) and a final participated lesson for summarizing
the concepts encountered in the labs also through data analysis, connecting them with their current knowledge and their future professional practice (3 hr). The first lab was performed in Department of Physics, while all other activities were realized at the school (microbiology laboratory and classroom). In the laboratory, students were assisted by one or two of the authors (V. M. and R. B.) with the collaboration of the teachers who were accompanying the class (usually 2 or 3, i.e. a physics teacher, a technical assistant and/or a support teacher for students with special needs). The final lesson was held by the author with more experience in winemaking and winery (R. B.) assisted by another author (V. M.) while teachers attended. We designed some materials, described in the next section, for facilitating comprehension of students, supporting them in laboratory activities and in preparing of final reports. We planned to evaluate the effectiveness of this action by means of direct observations performed by the authors during the activities with students, interviews with teachers for understanding the impact on motivations and learning achievements and, finally, by analysing students final reports.

**Materials**

*Laboratory on thermal equilibrium.* Students worked in small groups, but individual reports were requested. They started by observing the thermal equilibrium between solids (same mass and material, different mass and same material, same mass and different material) and solid/water in a Dewar flask. Then, a measure of heat capacity was realized. We focused on measures and error evaluations. Since this first experience in laboratory was very intense, we prepared a detailed worksheet in which all activities were explained, with some hints (e.g. there was indicated where to write a measure with spaces for error and measure units, space for calculation, data analysis and discussion). Therefore, students could follow the activity and, by completing the worksheet in class and at home, they had a ready report for assessment.

*Laboratory on changes of state.* The activity was to study the behaviour of water and water-alcohol solution at the boiling point and to compare them. We did not give any worksheet in this case.

*Laboratory on the Malligand ebulliometer.* Since the boiling temperatures depend on the local atmospheric pressure, the zero point of scale must be fixed. Water was placed in the boiler of Malligand’s device, the lamp was turned on and the zero of the sliding scale was fixed when it was coincident with the point of maximum extension reached by the mercury’s meniscus in the capillary. Then, the water was replaced with the same water/alcohol solution that they had examined in the previous lab. The device was heated again, and the value in alcoholic degrees could be read directly on the scale, in correspondence with the maximum point reached by the mercury.

Also in this case, we did not give any worksheet and we required a final report with data analysis and discussion at the end of the learning path (i.e., after the final lesson).

*Final lesson.* After all the activities in laboratory, students were guided in understanding their measures and physics processes involved in Malligand ebulliometer by a guided discussion and by a set of questions such as:

- By analyzing the time-temperature graph relative to boiling water can you deduce if and when the temperature is proportional to the energy supplied by the heater?
- What can be inferred in the case of boiling mixture, comparing to what happened in the case of water alone?
- The tool that you know more similar to Malligard’s device is ..................... Explain why.
- Can you explain why the scale is not linear?
- You have a graph which shows the boiling temperature of a mixture of water-alcohol as a function of composition of the mixture; how it is connected to the non-linearity of the scale of the Malligand’s device?
- The alcohol content measured with the Malligand ebullioscope is greater when the meniscus has less displacement. Do not you think it works differently than other scales?
All students received the complete set of questions and the chart of boiling point in function of composition of liquid mixture (similar to the one shown in Figure 2) in order to get some hints on all important aspect in the use of Malligand ebullioscope that can be inserted properly in the final report.

Our intent was that the two individual reports were collected by teachers for assessment of students at school. Moreover, we asked to have back all reports at the end of scholastic year for evaluating the effectiveness of the learning path.

**Participants.** All second classes of the Agricultural Technical Institute participated (5 classes, about 100 students aged 15-16 years).

**Data and findings.** Since the learning process lasted until near the end of the scholastic year, it was not possible to obtain the final reports of the students (only 20 reports of the first laboratory and 13 final reports of a single class were available, while all the others were missing although they were assessed by teachers). Thus, it was impossible to make directly a quantitative assessment of learning findings and we must limit ourselves to what emerged from direct observations through the activity, interviews with teachers and few observations on the available reports. In the laboratory as well as in conclusive lesson in class, students were interested and active, even though the level of attention could fall during complex tasks, especially theoretical one. Most of them were able to put data in a graph and connecting it to phenomena (seen and unseen directly). In Figure 3, data from a group of students is showed. The graph refers to the second experience in laboratory and during discussion in class many students were able to connect properly the time of heating of a constant heater, heat transferred to the liquid, variations of temperature, changes of state and how Malligand’s device works. Students were usually very careful in performing activities in laboratory, as shown in Figure 4, where a group was following the mercury’s meniscus in the capillary by using a flashlight as suggested by some of them. During the discussion, few students seemed to have captured the relationship between data on boiling point of a mixture, showed in Figure 2, and the non-linearity in the scale of the Malligand ebullioscope. However, more students were able to understand how the atmospheric pressure affects the measurement of the alcoholic strength and the importance of the initial set of zero point. Teachers reported a wide interests of pupils, especially for the part in laboratory, and gave a judgment generally very positive for the activity.

**Discussion and Conclusions**

The main purpose of increasing students’ attention on physics has been fully achieved. As soon as students realized the relationship with some aspects of enology, their involvement increased significantly. A first analysis of students’ reports on laboratory experience shows the necessity of paying more attention for integrating this activity in the previous knowledge of students. Another aspect that negatively affected the learning process was the lack of involvement of teachers in the initial design. This fact has led to a lack of involvement in making decisions during the educational process and a little incisive action towards students.

Anyway, these results convinced us to expand the topics of physics that can lead to activities directly usable in technical matters. Actually, we are designing and realizing learning paths, such as mechanics in the winery (winepress), fluid mechanics (hydraulic press, decanting wine, vats’ usage), optical (grape refractometer), in close collaboration with physics and vocational teachers in the same school. The idea is of preparing and testing learning paths spread over two years in which the main physics topics would be introduced to explain the functioning of tools and equipment used, normally, in the winery.

**Acknowledgement**

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Figure 1. On the left, the original drawing of the Malligand ebullioscope in the patent is shown. On the right, a schematic drawing, with the labelled parts cited in the text, is shown and a picture of the devise utilised by students is given.
Figure 2. Boiling point in function of liquid composition of a mixture of ethanol and water at a fixed pressure (WIKI Chart).

Figure 3. Temperature dependence from time is showed, when constant heat is supplied to the liquid. The data were collected by a group of students during the laboratory on changes of state.
Figure 4. Students are carefully following the mercury’s meniscus on the Malligand’s device aided by a flashlight.
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An empirical study on a learning path on wave physics focused on energy

Vera Montalbano and Simone Di Renzone Department of Physics, University of Siena, Italy

Correspondence concerning this article should be addressed to Vera Montalbano,
Department of Physics, University of Siena, via Roma 56, 53100 Siena, Italy.
E-mail: montalbano@unisi.it

Abstract

We describe an extracurricular learning path on waves focused on energy transfer. The advantages of introducing mechanical waves by using the Shive wave machine and laboratory activities are presented. Laboratories are realized by inquiry, i.e. students explore waves behavior in qualitative way, guess what can happen and suddenly test their hypothesis. Recently, we presented some disciplinary knots that arise usually in empirical investigation, according to the Model of Educational Reconstruction and discussed methodological choices made in designing the learning path and preliminary result about its realization with few, interested and talented pupils. We report the second year of this learning path performed with the same students that are introduced to more complex topics such as analogy in wave phenomena and resonance. Laboratories are described with particular attention for the energy transformation. We planned activities by focusing on conceptual issues such as characterization of the oscillatory motion and energy aspects vs. characterization of wave energy and energy transport. We designed the activities in order to propose a complementary experience compared to what was done in class. Despite resonance is a relevant phenomenon which runs through almost every branch of physics, many students have never studied it. Yet, resonance is one of the most striking and unexpected phenomenon in all physics and it is easy to observe but difficult to understand. Students performed activities in laboratory on several resonant systems. Our purpose was to outline how it is possible to tune a system or a device in order to obtain resonance and an efficient energy transfer from different physical systems, such as a mechanical one and an electrical one. This year, the final task was to analyze different natural phenomena in order of choosing one suitable for energy transfer. We present our considerations on the students’ learning process and on the possibility of extend a similar path in a classroom.

Keywords: wave phenomena, resonance, energy transfer, analogy

The description of wave phenomena in physics involves fundamental concepts that are difficult for many students (e. g. Wittmann, 1998; Wittmann, Steinberg, & Redish, 2003; Ambrose, Heron, Vokos & McDermott, 1999). Understanding and using functions of two variables, distinguishing between medium properties and boundary conditions, recognizing consequences of local phenomena in extended systems are few examples. More advanced topics, such as analogy, superposition or resonance, can be introduced simply or only in this context. Energy transport is another relevant topic in wave physics. Despite being such an interesting topic for students considering the economic, social, environmental and technological implications, it is rarely discussed at school.

Recently, we began to design learning paths on wave physics with the purpose of improving the achievement of students in this strategic topic. Since we used a methodology and laboratory activities quite different from standard teaching in our context, we designed an optional laboratory for performing a pilot investigation with students in secondary school within National Plan for Science Degree (Piano nazionale per le Lauree Scientifiche, i.e. PLS). Testing these activities with high school students can be considered the first step in order to develop a designed-based research learning path (Jonassen, Cernusca, & Ionas, 2007; Hake, 2008; Ruthven, Laborde, Leach, & Tiberghien, 2009).

The main aim was orienting toward physics in a more effective way, by introducing interested and talented students in wave phenomena through a most insightfully path. According to the Model of Educational Reconstruction (Duit, Komerek, & Wilbers, 1997; Duit, 2007), we identified some disciplinary knots that arise usually in empirical investigation (Di Renzone, Frati, & Montalbano, 2011).
Thus, we planned two extracurricular learning paths on waves, by following the guidelines of PLS. In the next section, we report the methods and details of the investigation that was designed with a duration of 3 years. In the following section, we describe some relevant aspect and findings, in particular for the second year of the investigation. Finally, in the last section we discuss the preliminary results obtained until now.

Learning Paths on Waves

Overview
In recent decades it has been detected almost everywhere a consistent decrease of graduates in science disciplines. The situation in Italy was dreadful. Thus, the Ministry of Education and Scientific Research promoted a wide project in order to reverse this trend: National Plan for Science Degree (for a survey on PLS and all actions realized locally in this context see Montalbano, 2012). A relevant role in the plan is played by PLS laboratories. Our test with students were realized as optional extracurricular PLS laboratories while all the design activities of learning paths were developed and implemented within two courses of the Master in Physics Educational Innovation and Orienting (a PLS action in professional development for teachers, for more details see Montalbano, Benedetti, Mariotti, Mariotti, & Porri, 2012) in which one author is enrolled (S. D. R.). Our proposal consisted in two deepening laboratories for selected students titled Waves and energy and Sound and surroundings.

Methods

The design was focused on conceptual issues, such as characterization of the oscillatory motion, wave energy and energy transport, and methodological issues in order to propose a complementary experience compared to what was done in class. Students ended their learning path on waves and sounds in class before laboratories started. Moreover, their class made an instructional trip to our department and performed a standard laboratory experience on diffraction and interference with light.

Both learning paths followed closely a type of PLS laboratory: Deepening laboratories for motivated and talented students. According to PLS strategy, they were orienting to science by means of training, students were the main character of learning and laboratory was thought as a method not as a place. Moreover, all activities arose from joint planning by teachers and university.

Since in previous PLS activities, we found a real effectiveness in active and cooperative behavior of students in laboratory (Benedetti, Mariotti, Montalbano, & Porri, 2011), we organized all meetings with a short introductory discussion followed by an experimental session in which students could explore waves behavior in qualitative way, guessing what could happen and suddenly testing their hypothesis. The realization by inquiry was utilized every time it was possible even when quantitative measurements were requested.

For evaluating the effectiveness of learning process we utilized direct observations in laboratories, resuming reports on measures requested to students at the end of relevant activities, annual final reports that students gave to their physics teacher for assessment of PLS laboratory in the school.

The laboratories were optional and the activities took place in Physics Department. We planned to meet students for 3 hours almost every month and to continue for the last 3 years of high school for a total of about 15-18 hr every year. We decided that for the first year both laboratories had the same introductory activities on waves physics and all students worked together (for a survey of activity in the first year, see Di Renzone, Fratt, & Montalbano, 2011). In the second year, we decided that some other activity could be discussed by the two groups of students together or performing the same experiment with different tasks. In particular, this happened for the activity in which resonance was introduced and for all activity and discussion about similarities in physics. Thus almost an half of meetings were still joined at least in the introductory part.
Waves and Oscillations

Activity description. Waves were characterized in laboratory by using a Shive wave machine (described in details in the next section). Students were free of exploring and manipulating the device for having a prompt qualitative overview of phenomena. Then, some hint was given for obtaining quantitative information by using a camcorder. Students used Shive wave machine for studying: Wave dependence on space and time, Impulsive and periodic waves, Longitudinal and transverse waves, Wavelength and frequency, Energy transfer, Speed of propagation, Superposition principle, Reflection and transmission, and Energy conservation.

Sound waves were studied by using a microphone and an oscilloscope as an example of longitudinal waves. Students verified the principle of superimposition in this case and studied beats and patterns of periodic beats (Moiré fringes). Interference was studied for sound waves in order to stimulate reflection around similarities and differences between different kinds of waves (longitudinal vs. transverse, three-dimensional vs. two-dimensional, and so on).

In the second year, resonance was introduced through a mechanical system, a magnet suspended from a spring which can be forced by induction with an electromagnet. Students studied this system and others focusing on energy transfer, in the case of conservation as well as dissipation. Some other system, such as a vibrating string and a RLC circuit, were analyzed in order to clarify the concept of natural frequency of a system and how can be changed by changing some system property. At this point, we arrived to introduce spectral decomposition of a broad signal and an example was given on dependence from boundary condition (vibrating string and resonant acoustic cavities).

Spectral analysis of solar white light, of a spectral lamp, of a laser beam and of a human sound comparison allowed students to start considering similarities in physics.

The final part of the second year was dedicated to considering energy transfer between mechanical or electromagnetic devices and natural phenomena. A research was made about which natural phenomena can be used as a suitable source of renewable energy.

Participants. Three students of 3th class in Liceo Scientifico Aldi in Grosseto (starting age 15-16).

Sounds and Surroundings

Activity description. The activities were common with wave learning path until resonance and spectral decomposition, but specific aspects were outlined such as the relevance of RLC circuit in modern musical instruments, many examples of resonant acoustic cavities were given and sometimes studied in detail.

In order to clarify the difference between one and two-dimensional vibrating systems a specific activity was performed in which students studied resonance in the case of metal sheets of different shape and acoustic waves.

Participants. Three students attending 3rd class of a Scientific High School (Liceo Scientifico Aldi in Grosseto), starting age 15-16. In the second year another student, belonging from the same class of other participants, joined.

Relevant Aspects on Designing and Findings

Overview

We designed the learning path in the way showed in previous section in order to focusing on the following conceptual knots in which the main difficulties in learning usually appear:

- Waves as function of several variables; this usually is an hidden trouble. Even brilliant students can use for long times functions of one and two variables without any real understanding of differences.
- Superposition principle is a fundamental concept and can clarify many phenomena in wave physics.
• Energy transport in order to distinguish waves from other periodic phenomena and comprehend many applications.

• Analogy in waves phenomena; difficulties are very common and reported (Podolefsky, & Finkelstein, 2007), especially in recognizing the same behavior in different context such as total reflection, diffraction, beats, interference and so on.

• Resonance; despite it is a relevant phenomenon which runs through almost every branch of physics, it is easy to observe but difficult to understand.

In the following, we want to describe advantages of introducing waves analysis by means of a Shive wave machine and the activities that, we believe, were more interesting and relevant for students learning process in this second year (for a summary of the first year relevant activities, learning problems and discussion, see Di Renzone, Frati, & Montalbano, 2011).

**Shive Wave Machine**

This device, showed in Figure 1, was developed by Dr John Shive at Bell Labs in ’50 (Shive, 1959), and consists of a set of equally-spaced horizontal rods attached to a square wire spine. Displacing a rod on one of the ends will cause a wave to propagate across the machine. Torsion waves of the core wire translate into transverse waves. Measures were obtained by using a camcorder and extracted from the captured images.

We chose Shive wave machine for characterizing mechanical wave because of easy and full interaction that allows to students. Measures of period, frequency, wavelength, speed of waves are straightforward; energy considerations, qualitative and quantitative tests are easy to perform. Stationary waves, reflection and resonance (or absence of it is) are simple to achieve and study. The main limit of the Shive wave machine is given by the fact that it produces a well-defined one-dimensional wave. Therefore, it is not possible to study refraction, diffraction and interference by using this device.

The enjoyment that students showed in using Shive wave machine and the forthcoming usage convinced us to utilize it also in the third year by constructing a tuneable system for transferring energy from it to an electric device.

**Similarities in Physics**

Shive Wave Machine was developed in order to point out similar features of waves as they propagate, reflect, superpose, resonate, etc. (Shive, 1959; Shive & Weber, 1982).

Analogies were displayed among the behaviours of waves on mechanical, acoustical, electrical, optical, electromagnetic systems every time that an activity in laboratory could be used for this purpose. Students were invited to consider different wave phenomena and find speed, frequency an wavelength range for:

• Mechanical waves: ripple tank, vibrating string, vibrating membrane, ...

• Pressure waves: sound, ultrasound, ...

• Electromagnetic waves: radio waves, microwaves, light, infrared, ultraviolet, X rays, gamma rays, ...

Then, they had the task of recognizing transverse and longitudinal waves, beats, reflection, refraction, interference, diffraction, Doppler effect in these different phenomena. In Figure 2 and 3 are shown two examples of refraction we gave, i.e. for a wave in liquid surface and for sound. We intentionally left students free to include other phenomena in each class if deemed appropriate and interesting. Thus, they proposed infrasound and seismic waves; an interesting discussion emerged from deepening the definition of radio waves.
Resonance

In order to introduce students to resonant systems, we proposed a mechanical system, a magnet suspended from a spring which can be forced by induction by an electromagnet (a schematic set-up is given in Figure 4). Students studied this system focusing on energy.

Electromagnetic induction can easily transform mechanical energy into electrical energy. Moving magnet induce a electromotive force in the solenoid that can move electrical charges (see Figure 5). Enveloping the outside of the electromagnet with aluminium is possible to observe the damping due to eddy currents.

Students studied the electromagnetic damping in a quantitative way in the case of a pendulum in which the mass was a magnet, showed in Figure 6.

Can induction transform electrical energy in mechanical energy? Students discovered that this is not always possible. If they tried to modulate an electromagnet, only in few cases the energy transfer was massive. They changed frequencies in the system in Figure 4 and observed that only for one frequency there was a massive oscillation of the mechanical system. They measured the period of the oscillating system without electromagnet and compare the frequency with the one measured before discovering that it was the same. Only if the two systems, electromagnetic and mechanical, were oscillating at the same frequency they can exchange a large amount of energy. Since the mechanical system had only few natural frequencies this happened only in few cases. Students were able to discover another frequency, different from the one of spring-magnet system, which corresponded to an oscillation like a pendulum of the magnet.

Students in the learning path on sounds performed another experience for resonance. By using a speaker connected to a function generator, a resonant system could be obtained by placing a metal plate over it. When sound was resonant with one frequency of the plate, salt started jumping leaving from the vibrating surface and cumulating in fixed zones. The figures formed by salt (Chladni figures, see figure 7 for two example) depend on the shape of plate, material, thickness and boundary conditions (existence of constrained points). In this case is very easy to recognize resonance.

Discussion and Conclusions

These laboratories seemed to be very successful, but sometimes students showed some learning difficult, in collecting properly and in using correctly the experimental data in order to describe physical systems, because they are little accustomed to face open situations. Students were very smart in using new device or in simple lab task such as measure of a period, but they showed a certain naivety in dealing with open problems.

Moreover, they were very active in laboratory but we obtained few elaborated materials. Every time we gave a task to complete by themselves at home, it was difficult to have back reports in a reasonable time and usually they were little accurate. We believe that the fact that their teacher was present only for reading the final report is the reason of this lack of care in activities performed at home.

The few involvement of the physics teacher implies also that all observations that we made in the students’ response and all suggestions that we can give for improve and integrate this learning path with the teaching process at school are postponed. In this way, it is very difficult to foresee a direct impact of this experience on the practice at school.

On the other side, reflections and conclusions that we can draw from the results obtained so far are in the direction that these learning process can be performed at secondary school, at the price of a hard work for teachers, but likely they would be more useful in a dedicated course for undergraduate students.

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References


Figure 1. The Shive wave Machine is showed. A student has just perturbed an extremity for obtaining a pulse travelling from left to right in order to understand what happens when a wave encounter a discontinuity in the medium (left and right part of the device are connected and made by rods with different length). This figure is a frame from the camcorder; by analyzing different frames, students were able to measure the speed of waves in the two part of Shive wave machine. The blue light belongs from a video projector and was optimized by students for video recordings.

Figure 2. On recognizing Snell's law for waves on a liquid surface.
Figure 3. Sound refraction from temperature gradients (Sound refraction).

Figure 4. A schematic set-up for the resonant system. A ceramic magnet was suspended from a spring on an electromagnet. The driving force in the experimental setup was supplied by a solenoid. To allow its modulation, a mosfet transistor was used as an electronic switch. A function generator applied a square wave of given frequency to the mosfet gate, resulting in a modulation of the DC current provided by the power supply to the solenoid. The solenoid forced the magnet to oscillate at the same frequency of the square wave: changing the frequency it is possible to study the resonant condition of the magnet-spring system.

Figure 5. On the left a schematic set-up is showed. On the right, a picture of the display of an oscilloscope shows the electromotive force induced at the terminals of solenoid. Finally, a graphic obtained by a simple simulation allows to explain the form of the electromotive force in terms of velocity (green line) and distance from solenoid (red line) of the magnet.
Figure 6. A schematic set-up of experiment of pendulum damping is showed on the left. A ceramic magnet was suspended on a solenoid. Students visualized the electrical tension at the terminal of solenoid on the display of an oscilloscope. Copper plates were placed on the electromagnet for studying damping vs. thickness of the metal. On the right a picture of the display of oscilloscope shows the exponential damping.

Figure 7. On the left a Chlandi figure is showed for a round sheet. On the right, a different picture for a rectangular sheet is given.
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Ten Reasons to Give Credence to Anthropogenic Climate Change

Gordon J. Aubrecht, II, Department of Physics, Ohio State University Marion, Marion, Ohio USA, aubrecht.1@osu.edu

Abstract

Any course of action has costs and benefits. To obtain the benefit, we need to pay the cost. No power plant pollution means no power plants. No power plants means no electricity. No electricity means no modern surgical procedures, no medical diagnostics, no comfortably lighted and cooled homes, etc., all things most people want to have or at least have available to them. One consequence of human use of energy is emission of greenhouse gases. Many nonscientists (as well as a few real scientists) do not think that climate change could be caused by human actions. Reasons range from doubt that tiny humans could affect an entire planet to belief that human life on Earth will soon end. Science is about experimental data, reasoning from those data, and theoretical perspectives supported by the data. Svante Arrhenius provided (in 1896) the first theoretical (and compelling) reasons that carbon dioxide could influence Earth’s energy budget. Multiple sources of modern data underlie the belief of virtually all climate scientists that humans are changing the climate. The evidence is based on temperature measurements, satellite observations, ice-core sampling, statistical analyses, sea level measurements, observations of plant and animal behavior, and other sorts of measurements. The nature of science is something that should be shared with students and fellow citizens, and an important feature of science is its reliance on evidence. We provide ten evidentiary reasons to accept that humans cause climate change.

Introduction

There are ten reasons we can give for accepting the human factor in the changing climate. They are that (1) Earth is not at 255 K; (2) Earth’s stratosphere is cooling while the troposphere is warming; (3) Satellite measurements show that less radiation escapes to space than before; (4) Non-peer-reviewed claims that weather stations’ location caused the “apparent” warming in average temperature have been withdrawn by the person who originally made them, in peer-reviewed literature; (5) Earth’s temperature is rising, particularly since 1980; (6) Most continental glaciers are receding and Arctic sea ice is declining; (7) Sea level is rising, and the oceans’ pH is changing; (8) Species of animals and plants are moving toward the poles; (9) Climate change is already affecting people; and, finally, (10) Nights are warming faster than days. Additionally, it is regular science, just as ours is, and there is a real consensus among experts that humans are implicated.

Method

There is little dissent about the existence of the “human fingerprint” among knowledgeable climate scientists.

We examined the climate literature to determine factors that experts think affect our climate for the revision of our energy book for its fourth edition (Aubrecht, 2006). We found a general consensus that human beings were affecting climate. Among the many peer-reviewed articles that were read, very few claimed that humans had no effect.

Data and findings

1. The greenhouse effect depends on the concentration of carbon dioxide

Earth is not at 255 K. Without the greenhouse effect, radiation balance with an airless Earth determines that equilibrium temperature. Earth’s mean temperature is about 288 K (15 °C). Carbon dioxide is the main natural greenhouse gas, and feedback with water vapor leads to that global temperature.

The U.S. economy, much like that of the entire world, runs on fossil fuels—34 Gt/yr CO₂ emissions; there has been a 40% increase in CO₂ concentration since the start of the Industrial Revolution. Fig. 1 shows how complete is the U.S. reliance on fossil fuels. Almost 80% of the energy economy is carbon based.

Fig. 2 shows how carbon dioxide emissions have grown since 1750. The industrial revolution appears quite visibly around 1850. This graph also shows how much the atmospheric burden of carbon dioxide has increased since the end of World War II. The year 1945 was the last of the war effort with factories going all out, yet emissions are currently more than 7.5 times as great as they were in 1945. Earth’s population was slightly above 2 billion in 1945 and is 7 billion today, so the carbon dioxide emissions increase is over twice as much as can be attributed to population growth. (To determine the release of carbon dioxide from the graph, you must multiply the mass release by 44/12, the ratio of molecular mass of CO₂ to the atomic mass of carbon: for 2009, the 8738 Mt of carbon emitted translates into a bit over 32 Gt of CO₂.)

Figure 3. Greenhouse gases over the past two millennia. IPCC (2007), Working Group 1 report, p. 135, Fig. FAQ 2.1, Figure 1.

A broader perspective is found in the 2007 report of the Intergovernmental Panel on Climate Change (IPCC). Fig. 3 shows the greenhouse gas emissions over the past 2000 years. Fig. 4 shows the history of greenhouse gas emissions over the last 20,000 years. This emphasizes how anomalous the past 150 years have been in terms of emissions.

This is of great concern because (as is described below) warming is causing melting of ice and other effects more strongly than near the tropics, as was predicted by Manabe and Weatherald (1967). Permafrost harbors methane (a strong greenhouse gas, as indicated in Fig. 4) that can be released, perhaps in amounts that will greatly enhance warming through positive feedback. In the past, Earth’s warming has been linked to massive releases from permafrost (DeConto, 2012). They show that high temperatures in the early Eocene took place when the Milankovich variables eccentricity and obliquity were high. They claim that “the magnitude and timing of the PETM and subsequent hyperthermals can be explained by the orbitally triggered decomposition of soil organic carbon in circum-Arctic and Antarctic terrestrial permafrost.” They further assert that petagrams (gigatonnes) of carbon had to have been released during these intervals of high temperature.

There had been concerns about the understanding that carbon dioxide was a consequence rather than a cause of warming. This arose because of data from Antarctic ice cores that indicated that warming preceded increased carbon dioxide concentrations. A recent analysis of data (Shakun et al., 2012) from around the world for the period between 10 and 20 thousand years ago shows that Antarctica was an anomaly—that for the rest of the globe, increased carbon dioxide concentrations preceded the increase in temperature. The authors use eighty “globally distributed, high resolution proxy temperature records” to find the temperature during this period. The authors write “we suggest that the increase in CO₂ concentration before that of global temperature is consistent with CO₂ acting as a primary driver of global warming, although its continuing increase is presumably a feedback from changes in other aspects of the climate system.”

As for Antarctica, Shakun et al. suggest that “internal heat redistributions explain the lead of Antarctic temperature over CO₂ while global temperature was in phase with or slightly lagged CO₂.”
Figure 4. Greenhouse gases over the past ten millennia. IPCC (2007), Working Group 1 report, p. 25, Fig. TS.2. “The concentrations and radiative forcing by (a) carbon dioxide (CO2), (b) methane (CH4), (c) nitrous oxide (N2O) and (d) the rate of change in their combined radiative forcing over the last 20,000 years reconstructed from Antarctic and Greenland ice and firn data (symbols) and direct atmospheric measurements (panels a,b,c, red lines). The gray bars show the reconstructed ranges of natural variability for the past 650,000 years.”

2. The stratosphere is cooling, the troposphere is warming

Figure 5. Temperature profile in the atmosphere. (Thompson and Solomon, 2005)
Data indicate that Earth’s stratosphere is cooling while the troposphere is warming. This effect was predicted in the 1960s (Manabe & Wetherald, 1967). Recent data from Thompson and Solomon (2005) show that this has been the case. Fig. 5 shows these data. Data summarized by Randel et al., (2009), corroborate this observation (Fig. 6).

Figure 6. Temperature profile in the atmosphere. (Randel et al., 2009)

3. More radiation stays near Earth’s surface

Satellite measurements show that less radiation escapes to space, as seen in Harries, H. E. Brindley, Sagoo, and Bantge (2001). Friend (2011) looked at Earth’s response to forcing over the last two millennia. He suggests that solar variability might be overestimated as a cause of climate change.

Figure 7. Change in Earth’s emitted radiation. (Harries et al., 2001)

4. Weather stations’ locations have been falsely blamed for “false” warming

D’Aleo and Watts (2010) show multiple pictures of weather stations that might have higher-than-average temperatures being reported. However, they neglect to note or may not have known that the stations reports are being monitored not for measured temperature, but rather what are used are temperature anomalies.

Fall et al. (2011), whose authors include Watts, find among the stations that “statistically significant differences remain for all but average temperature trends.” By this, they mean that average temperatures are unaffected by the proposed station bias, but reported high and low temperatures do depend on siting
(“the accuracy of maximum and minimum trend estimates can be improved by using only better-sited stations”). Menne, Williams, and Palecki (2010) agree with this result. Additionally, Muller et al. (2011) write “Although our analysis was done using only US land stations, it indicates that the poor station quality documented by Fall et al. (2011) should not significantly bias estimates of global warming.” They further find that the effect of poor station siting on temperature “trends is small and – at least for the data from 1957 onwards – amounts to changes of less than 0.02 °C since 1957.”

5. Earth’s temperature is rising, particularly since 1980

Data from the National Oceanic and Atmospheric Administration shown in Fig. 8 from the instrumental temperature history of the globe show how temperature has changed over 130 years. A different view is visible in Fig. 9. Here are the individual years and number of months in that year among the 25 warmest (+) or coldest (-). You can see that 1883, 1884, and 1956 were anomalously cold and 1995, 1997-1999, and 2001 onward were anomalously warm. (I use more than nine months in a year among the coldest or warmest as a measure of anomaly.)

![Figure 8. Instrumented temperature history 1880-present. NOAA](image)

**Figure 8.** Instrumented temperature history 1880-present. NOAA
Figure 9. NOAA data showing the 25 warmest (red) and coldest (blue) months by year of occurrence.
Also, Guirguis, Gershunov, Schwartz, and Bennett (2011) show that temperatures have become more extreme in recent times. Büntgen et al. (2011) have produced a record of European temperature over 2500 years that shows that current temperatures are far higher than at any other time in the record.

Figure 10. a. January changes. B. July changes in minimum and maximum temperatures. NOAA 2012
Even over a short period of time, the 30 year rolling “normal” has changed substantially. Fig. 10 shows the NOAA (2012) new normals.

6. Continental glaciers are receding and the Arctic ice sheet is melting

The Greenland Ice Sheet has fluctuated in size, while undergoing a decline since about 1953. During July, 2012, virtually the entire surface was undergoing melting.

In September, 2012, the Arctic Ice cover declined to its lowest ever recorded. According to the NSIDC (2012), “Each year the Arctic sea ice reaches its annual minimum extent in September. It hit its previous record low in 2007. This summer’s low ice extent continued the downward trend seen over the last 33 years. Scientists attribute this trend in large part to warming temperatures caused by climate change. Since 1979, September Arctic sea ice extent has declined by 13 percent per decade. Summer sea ice extent is important because, among other things, it reflects sunlight, keeping the Arctic region cool and moderating global climate.” Fig. 11 shows this effect.

Further, Fig. 12a (NSIDC, 2012) shows that, compared to the last two decades of the twentieth century, Arctic sea ice has declined precipitously. Fig. 12b (U.S. Global Change Research Program, 2009) shows annual average sea ice extent since 1900, showing a decline beginning in the early 1950s. Many studies have documented the decline in continental glaciers, almost all of which are receding. See, for example (Vuille et al., 2008).
Figure 10. Arctic sea ice extent for September 2012 was 3.61 million square kilometers (1.39 million square miles). The magenta line shows the 1979 to 2000 median extent for that month. The black cross indicates the geographic North Pole. NSIDC, 2 October 2012.

7. Sea level is rising, the oceans are warming, and the oceans’ pH is changing

There is evidence that sea level rise is accelerating at 0.013 ± 0.006 mm yr⁻² (Church and White, 2006). Several meters of sea level rise are expected to occur over the next few centuries (IPCC, 2012), but exact projections such as in Fig. 13 depend on which IPCC scenario is used. Fig. 14 (Roemmich, Gould, and
Gilson, 2012) shows that the ocean has warmed substantially over the last 135 years since the H.M.S. Challenger measurements.

**Figure 13.**

a. Sea level rise data. Reisman 2009

b. Data and projections for the 21st century using the IPCC SRES A1B scenario. IPCC 2012.

In several papers, Rahmstorf (2012) has questioned the IPCC sea level rise projections as too low. He notes that “A number of recent studies taking the semi-empirical approach have predicted much higher sea level rise for the twenty-first century than the IPCC, exceeding one meter if greenhouse gas emissions continue to escalate.” In Schaeffer, Harel, Rahmstorf, and Vermeer (2012), the authors estimate that even if warming is held to 1.5 to 2 °C above the preindustrial level, sea level will still rise 75 to 80 cm above year 2000 levels. In many projections through the next several centuries, sea level rise exceeded 2 meters if the temperature increase exceeds 1.5 °C. Only by holding the increase under 1.5 °C do the models give a plateau of 0.9 to 2.4 meters of rise.
Figure 14. Argo-minus-Challenger ocean temperature difference (black line gives all-station averages over 135 years). Roemmich, Gould, and Gilson, 2012.

Ocean pH (Fig. 15) is changing toward more acidic at a rate unprecedented (Kerr 2010) in the last 25 million years (European Environment Agency, 2012). The acidification in the Pacific Ocean has been observed directly (Byrne et al., 2010). Guinotte and Fabry examined the known effects of acidification and determine that “biological effects of ocean acidification is in its infancy and the long-term consequences of changing seawater chemistry on marine ecosystems can only be theorized.” They write that “effects of ocean acidification on less charismatic species and/or species with no economic value should not be overlooked. The biological response of marine organisms (both commercial and noncommercial) to ocean acidification will be key to making informed policy decisions.”

As air and water temperatures rise, marine species are moving northward, affecting fisheries, ecosystems, and coastal communities that depend on this food source. On average, by 2006, the center of the range for the examined species had moved 19 miles north of their 1982 locations, as seen in Fig. 16 (U.S. Global Change Research Program, 2009).
According to Yamano, Sugihara, and Nomura (2011), who studied corals in the region around Japan, “Four major coral species categories, including two key species for reef formation in tropical areas, showed poleward range expansions since the 1930s, whereas no species demonstrated southward range shrinkage or local extinction. The speed of these expansions reached up to 14 km/yr.”

There are many indicators of the effect of climate change on species. For example, Mexican lizards are not mating due to less basking and foraging time (Sinervo et al., 2010;). Huey, Losos, and Moritz (2010),
commenting on Sinervo et al., write “Global warming is expected to drive widespread extinctions, but predictions are rarely validated against actual extinctions and by knowledge of causal mechanisms. Sinervo et al. deliver a disturbing message: Climate-forced extinctions are not only in the future but are happening now.”

Many other land species’ ranges are changing (Chen et al., 2011; Saikkonen et al., 2012). Sheridan and Bickford (2011) claim that “[m]any species already exhibit smaller sizes as a result of climate change” and add that “[o]bserved and expected patterns of decreased body size are widespread across different taxa,” and they expect climate shrinkage will affect “an increasingly wide array of taxa over the coming century.” Marine species’ sizes are changing more than those on land (Forster, Hirst, and Anderson, 2012).

9. Effects have been and are being felt by people

There is even greater concern should warming exceed 7 °C; if extensive regions of Earth experience normal temperatures greater than 35 °C, mammals such as humans could be pushed out from large regions of Earth made uninhabitable due to heat stress (Sherwood and Huber, 2010).

Indeed, warming has been implicated in increases in conflicts. Using data since 1950, Hsiang, Meng, and Cane (2011) show “that the changes in the global climate driven by ENSO are associated with global patterns of conflict.” It was twice as likely that a conflict would erupt in a tropical country in an El Niño year than in a La Niña year (Hsiang, Meng, and Cane, 2011; Jones, 2011).

Zhang and coauthors (Zhang et al., 2006; 2007a; 2007b; 2010) found that cold years in China were more likely to lead to internal conflicts. Indeed, in Zhang et al. (2007a), the authors write “elevated levels of war outbreak and population decline in populated areas occurred during a cold climate in the past millennium. Europe and China are strong cases to illustrate that the links and feedback effects between temperature change and social events, long-term cycles of war outbreak and population decline, originate in large part from a fundamental driver, climate change.”

Zhang et al. (2011) have also studied the effect of climate on Europe through the period 1500 to 1800. They examined the Northern Hemisphere temperature anomaly, the Europe temperature anomaly, the ratio of grain yield to seed and Northern Hemisphere extratropical tree-ring widths the detrended grain price and detrended agricultural production index, the detrended wage index and number of famine years per decade, the number of wars and magnitude of social disturbances, the detrended human height (in cm) and the number of plagues per decade, the war fatality index, and number of migrations per quarter century. They established connections and tested them statistically. They write that “cooling from A.D. 1560–1660 caused successive agro-ecological, socioeconomic, and demographic catastrophes.” The authors assert that “climate change was the ultimate cause, and climate-driven economic downturn was the direct cause, of large-scale human crises in preindustrial Europe and the Northern Hemisphere.”

Concern over the effects of climate change on national security led to preparation of a report by the National Research Council to the U.S. intelligence community (Steinbruner et al., 2012). Among their conclusions are “To understand how climate change may create social and political stresses with implications for U.S. national security, it is essential for the intelligence community to understand adaptation and changes in vulnerability to climate events and their consequences in places and systems of concern, including susceptibility to harm and the potential for effective coping, response, and recovery. This understanding must be integrated with understanding of changes in the likelihoods of occurrence of climate events.” and “It is prudent to expect that over the course of a decade some climate events—including single events, conjunctions of events occurring simultaneously or in sequence in particular locations, and events affecting globally integrated systems that provide for human well-being—will produce consequences that exceed the capacity of the affected societies or global systems to manage and that have global security implications serious enough to compel international response. It is also prudent to expect that such consequences will become more common further in the future.” A major emphasis of concern in the many studies cited in this report is “[d]eclines in food and water security.” In addition, there may be, as a result, increased health risk.
Observers have noted that more extreme weather is predicted if temperatures rise. A warmer atmosphere holds more water and so storms can become more damaging and areas of excess wet and drought will develop. Chimou and Rahmstorf (2012) say that “heatwaves, but also precipitation extremes” are strongly linked to human caused warming, while larger storms are less clearly linked but still plausibly linked. According to Barriopedro et al. (2011) “there is an increasing likelihood of mega-heatwaves over highly populated areas of Europe with magnitudes such that they would exceed the exceptional current weekly-to-seasonal temperature maxima of [western Europe] within the next four decades and of [eastern Europe] afterwards. Given the disastrous effects of the 2003 and 2010 events, these results venture serious risks of simultaneous adverse impacts over large areas if no adaptive strategies are adopted.” European storminess over the past 140 years does seem to have been increasing (Donat et al., 2011).

McMichael (2012) finds evidence of large effects on civilizations from climate events: “(i) Long-term climate changes have often destabilized civilizations, ... (ii) Medium-term climatic adversity has frequently caused similar health, social, and sometimes political consequences. (iii) Infectious disease epidemics ... (iv) Societies have often learnt to cope (despite hardship for some groups) with recurring shorter term (decadal to multiyear) regional climatic cycles (e.g., El Niño Southern Oscillation)—except when extreme phases occur. (v) The drought–famine–starvation nexus has been the main, recurring, serious threat to health.” He goes on to assert that “[t]he greatest recurring health risk has been from impaired food yields, mostly due to drying and drought. The fact that drought has been the dominant historical cause of hunger, starvation, and consequent death casts an ominous shadow over this coming century, for which climate modeling consistently projects an increase in the range, frequency, and intensity of droughts.”

The National Research Council (Vaux et al, 2012) studied water issues consequent to climate change. Drought is the result when water is overcommitted, and the glaciers of the Himalayas are melting (as was already indicated, continental glaciers mostly are melting in response to warming). Part of the problem is the high population (about 3 billion people) of the regions of Asia partially dependent on meltwater from the glaciers. This water supplements water from rain and from aquifers and when the monsoon fails can become an important lifeline. Much of the world that has a Mediterranean climate (the southwest United States, southern Europe, northern Africa, the Middle East, and central Asia) already experiences water stress or deficit. Stress is defined as less than 1700 cubic meters per person per year; chronic scarcity as less than 1000 cubic meters per person per year, and absolute scarcity as less than 500 cubic meters per person per year (Vaux et al., 2012).

It is hard to discern the effects of climate on glaciers because the response lags the causes by as much as decades. Papers cited in Vaux et al. document rising temperatures in the majority of the region over the past 50 years. There are less data for the northwestern Himalayas and Karakoram region, and some indications of decreasing temperatures, so less clear trends than in the rest of the region. The study notes that huge floods are unlikely to occur if glaciers continue melting, but that dangers do include “flash flooding due to extreme precipitation, flooding due to monsoon rainfall, [glacial] lake outbursts, landslides, and avalanches.”

As the report points out, “access to reliable water is vulnerable to disruptions from intentional human actions or from changes in natural conditions, including climatic changes.” That is, water scarcity can lead to organized conflict, of which many have been documented (Vaux et al., 2012, Table 4.1). Given the uncertainty in supply, which the report suggests better measurement will help, “the most compelling need is to improve water management and hazards mitigation systems.”

10. Nights are warming faster than days

As a particular example, consider the situation in Wisconsin (Wisconsin Initiative on Climate Change Impacts, 2011). There the authors find that “winter temperatures increased significantly in northwestern Wisconsin, and these increases extended into the central part of the state. Springtime temperature increases also occurred in the same regions. During winter, nighttime minimum temperatures warmed at a faster rate than daytime maximum temperatures, and the number of very cold nights declined significantly. Northwestern and central Wisconsin experienced 14 to 21 fewer nights with temperatures below zero degrees Fahrenheit. Other areas of the state saw reductions in subzero nights of seven days or less.”

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“During summer months, daytime maximum temperatures across the state changed little from 1950 through 2006, but nighttime minimum temperatures warmed significantly in the northwestern and central regions.”

Alexander et al. (2006) present data in Fig. 17 that show cool nights decreasing as warm nights increase, while the trend for days is in the same direction, but somewhat smaller. Similar results were detected by Morak, Hegerl, and Kenyon (2011).

Figure 17. Annual time series anomalies relative to 1961–1990 mean values for annual series of percentile temperature indices for 1951–2003 for (top left) cold nights, (top right) warm nights, (bottom left) cold days, and (bottom right) warm days. Alexander et al. (2006)

March of 2012 was one of the warmest Marches on record. NOAA/NCDC (2012) recorded 7,517 records set or tied for the warmest nighttime low temperature at a weather station, 287 records were set or tied for the coldest nighttime low temperature at a weather station. They found that 7,755 records were set or tied for the warmest daytime high temperature at a weather station, and 603 records were set or tied for the coldest daytime high temperature at a weather station. However, this is not really much different than other recent months. For example, for July, 2011, the corresponding record numbers are 6,106, 443, 2,722, and 763. July, 2012 was recognized as extremely warm in the United States; its corresponding record numbers are 3,673, 325, 4,420, and 883.

Fig. 18 shows the warm (red) and cold (blue) records set in March, 2012. A few places in the Southwest and the Pacific Northwest were anomalously chilly, but most of the country was very warm.
Mishra and Lettenmaier (2011) looked at 60 years of trends in urban America and found a decline in heating degree-days, an increase in cooling degree-days, and warmer nighttime temperatures.

The 2003 European heatwave with its as many as seventy thousand excess deaths was a harbinger of things to come (Robine et al., 2008; WHO, 2012); the high mortality seems to have been caused by nighttime temperatures being too high for too long a long period of time. Stott, Stone, and Allen (2004) note that “it seems likely that past human influence has more than doubled the risk of European mean summer temperatures as hot as 2003, and with the likelihood of such events projected to increase 100-fold over the next four decades, it is difficult to avoid the conclusion that potentially dangerous anthropogenic interference in the climate system is already underway.” There was also a reported 30% decrease in European gross primary productivity (Ciais et al., 2005) as a direct result of the 2003 heatwave.

More heatwaves are expected; the Russian heatwave of 2010 (Barriopedro et al., 2011) and the American heatwave of 2012 were such heatwaves. According to Diffenbaugh and Scherer (2011), “permanent emergence of unprecedented heat in the tropical regions is likely to result in substantial human impact, particularly given previous humanitarian crises associated with severe heat.”

Discussion and Conclusions

One further reason for physicists to accept that climate is affected by humans is that it’s just the result of regular science, the sorts of things we do every day. Climate science is based on three pillars: basic physics, statistical analysis, and supercomputer simulations. Physics says, for example, humidity is higher in warm air. Obvious statistical trends are apparent in temperature and precipitation data. Detailed supercomputer simulations confirm the relationship between atmospheric warming and temperature and precipitation records.
Additionally, it is important to recognize that here is a scientific consensus. The first to address this issue was Oreskes (2004). Other authors found that 97% of climate scientists attribute warming to humans (Doran and Zimmerman, 2009), or that “97–98% of the climate researchers most actively publishing in the field surveyed here support the tenets of ACC [anthropogenic climate change]” (Anderegg et al., 2010). Rosenberg et al. (2010) surveyed climate scientists looking for differences and found that “[t]he homogeneity of climate scientists in our survey is an important finding and highlights the amount of cohesiveness among our respondents. Political orientation provided the only significant fault line and focused primarily on policy choices, not on the basic science foundations.” Lewandowsky, Gignac, and Vaughan (2012) highlight their finding that “[p]eople were more willing to attribute long-term climatic trends to human causes when they had been informed of the scientific AGW consensus, and they were more likely to accept as true the statement that human CO2 emissions cause climate change.” They suggest that highlighting consensus can be useful when communicating issues that “are difficult to grasp or are hotly debated or challenge people’s world views.”

This paper attempts to codify reasons to accept the consensus on the basis of common understanding of what science means, how it recognizes data, and how knowledge grows through replication, and on a recognition that consensus in science is a reflection of current understanding rather than politics. We have presented ten rather general streams of data that support and converge toward the cited consensus.

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*WCPE 2012, Istanbul, Turkey*


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Light as a Substance

Corrado E. Agnes, Department of Applied Science and Technology, Politechnic School of Engineering, Turin, Italy

Abstract

The subject is a broad project of science popularization, focused on light and mainly addressed to teachers. Its aim is to provide a frame of thinking, the analogy between light and a substance, to organize observations and experiments about the physical phenomena of light. The core of the project are 12 pictures executed by the graphic artists I appointed and instructed. The pictures represent observations and experiments with light, some more “gedanken” and unrealistic than others and they are meant to attract the attention with illustrations in the “comics” style and statements in the “slogan” style. Although the picture can make the show all by themselves, the project is expected to be interactive, with live hands-on experiments and aside materials.

Keywords: Light, Models, Popularization of Physics

Introduction

1. What is Light?

I believe in the need to avoid all such “ontological” questions in science education and much more in science popularization. Where they on the contrary pour out abundantly: the question “what is light?” prompts out answers like “light is pure energy” [Herrmann, Job 1996], which when not simply incorrect are anyway deeply misleading. That happens because the procedure of the contemporary popularization is to use the words only to appeal to imagination and to fill the void left in the physical discourse by the absence of mathematical formulas, within the widespread belief that “mathematics is the language of physics”. On the contrary, because the psychological science of education has since the cognitive revolution acknowledged that education is the production of meanings, Acts of Meanings obtained essentially Making Stories [Bruner 1990, 2003], I believe in the possibility to build a substantial understanding of physics through narrative understanding, with no unnecessary simplification and no dumbing down [Fuchs 2009, 2012]. So that an anti – rhetoric science dissemination is not only possible, but it can be considered the zero level of science education, delivered in the common language since primary school.

2. Light is a Physical System.

I used the analogy of a material substance for the physical system light, [Herrmann et Al. 1990], that is I tried to think of light as a kind of gas, with no odor, no flavor and invisible like tear gas, the one you notice only when it comes into your eye. This analogy builds a simple and effective “model” for the most controversial physical system and with the new particle it completes the traditional description with rays and waves. As if three models and four theories were not enough! To be precise I’ll use the word model in the following restricted meaning: a model is indeed a physical system whose behavior is known, taken as “model” to understand the behavior of a new and unknown system, and this can be considered the lowest level of explaining a physical phenomenon. In this sense a model cannot be right or wrong (compare how different with theories!), only useful or useless.

The model of light as a substance is already in use, even tough not officially recognized. The common language is “ready” to use this model as you can see from the following examples, where the light is considered a kind of stuff: the room filled up with light – filtering light – to absorb the light – to analyze the light – the synthesis of white light from different colours – pure light and composite light – ...
Recovering what is worth teaching in the old theories about the “simplest substances”, and keeping an eye wide open to the modern quantum theories of electrodynamics and thermodynamics, we get a representation of light which is both intuitive and narrative, and substantially correct from the point of view of physics.
The first illustration addresses the most important point of the proposed analogy: the failure of the most common property of substances, the conservation. Light is not Conserved – Light is Created (produced) and Annihilated (destroyed), directly against the “mantra: nothing is created and nothing is destroyed!”.
But at a closer examination any educt substance undergoing a chemical reaction can be considered vanished and any product substance can be considered created.

The story about the non conservation of light comes from a popular German tale.

It prompts the question: how could we have conserved the light?

With parallel mirrors! but only in theory of course. The darkening of the images indicates that light is absorbed. This theoretical limit of “conserved light” is highly interesting, being another way of obtaining the Light Gas, otherwise called “blackbody radiation”, devised by Planck, just adding a small particle inside the box of mirrors to absorb and emit radiation.
Light as a mixture of simpler substances and the rainbow is the paramount observation – experiment.

But the different colors, the different directions of movement, the different directions of polarization may be considered order parameters for light.

Not differently from the “substance” apples: size and color are the order parameters and you know trees are now being bred to grow “laser” apples: all of the same species, color and size!
Like any other substance, light has an elementary portion, whose name is well known, photon, but whose particle behavior has to be understood in a statistical way.

See the Tanamura two-slit experiment, where the mathematical rule for the localization of interference fringes are built photon by photon.
Light as any other physical system has many states and undergoes processes between them, but this is not evident. Light appears as a static whole. This seems a good point in favor of the analogy, but let me caution another time that the teaching strength of using analogies is when the analogy fails. So the continuous emission and absorption and flow of light is worth being demonstrated. We know light is invisible, the night sky is full of light but you need the moon as a paper sheet put in the way of light and diffusing it in all directions. The laser light is invisible until it is diffused by chalk powder. The same demonstration fails with a torch because its light naturally “opens up” much more than laser light. The spreading of light may be thought of as filling more and more volume, like the substance light expanding! and it is a good analogy that alike to a gas expansion it is an irreversible process.

We can make light flow together with the water flow, the very same idea of optical fibers
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Light as a carrier of information or data is common knowledge, also it is common knowledge that light heats, but think of the temperature of light: it becomes more acceptable in the substance model of the Planck’s light gas!

Moreover if light carries heat energy it must have entropy too! And it turn out that the simplest thermodynamic system is the Planck light gas. I'll make an exception and show the simple formulas relating energy, entropy, volume and temperature of light gas:

$$ S \propto V T^3 \quad E \propto V T^4 \quad j_E = T j_s $$

The gas analogy may go that far to consider the fossil radiation (3K cold), as the result of the isoentropic (adiabatic) expansion of the light of the big-bang.
Visiting the Show

Poster 8

Light moves something

light carries energy

Visiting the Show

Poster 9

Light rotates something

light carries energy
To demonstrate that light is a carrier of motion energy is a very refined experimental task and the explanation of this windmill is very controversial.

What can easily be demonstrated is that its motion cannot be due to radiation pressure! Look at the double windmill with the exchanged silver-black coat. If you do not want to buy this expensive demonstration use a mirror: this time it tells the truth!
Visiting the Show

Poster 11

LIGHT
reacts in a chemical way

light carries energy

Visit the Show
Poster 12

light has a chemical potential

light consists
of elementary portions

LIGHT
is a substance

Visit the Show
Poster 11
There are reactions, called photochemical reactions, the most known is the photosynthesis, in which light may be considered a substance among the other substances taking part to the reaction. Demonstrations are easily available: fluorescence sticks, thermo paper, UV beads, invisible ink, IR sensible material .... The interesting point is the possibility to use the old well known didactical tool, the chemical reaction with the new substance, symbol \( \gamma \).

Luminescence, for example, may be described as a chemical reversible reaction! Because of the night-day time interval it gives the impression of filling and emptying with light. Here is a good idea for a light jar, without solar cell inside!

The solar cell too may be explained as a reaction! A process where the only educt is light and the products are the “substances” \( n \) and \( p \) of solid state physics, indeed you know they are very different from the particles “electrons”.

And the prize for taking this view is to explain the LED light as the reverse of the previous reaction!

\[
\gamma \longrightarrow n + p \quad n + p \longrightarrow \gamma
\]

Summarizing the summary, light is a distributed physical system, endlessly emitted and absorbed and re-emitted by bodies, and because of that may be efficiently modeled by a kind of stuff.

**Conclusions**

The complete collection of posters in high resolution is available for downloading at [www.corradoagnes.com](http://www.corradoagnes.com) in English, German and Italian. The whole project is meant as a challenge to teachers, students and visitors about the following claim: any experiment with light may be simply explained, at the corresponding low level, with the analogy of light as a substance. Try it and I’m expectant to discuss on the website or email corrado.agnes@polito.it.

I really believe that the superiority of the substance model at beginners level is self evident, but what would be very profitable for physics education from the acknowledgement that light can be considered a material substance too, would be the end of “ontological” barriers like light and matter, energy and matter etc. Leaving science free to use its neutral words, instead of charging the words of science with meanings alien to science. So that the metaphors from natural science could resume its “natural” role in human culture. Let’s me conclude reminding the metaphor used by medieval monks to address the pregnancy of Virgin Mary, “light passing through a transparent medium”.

*Proceedings of The World Conference on Physics Education 2012*
Acknowledgements

The poster have been produced by the graphic artist Nadia Celeghini info@nadiaceleghini.com http://www.nadiaceleghini.com and designed by the firma Great Ads Comunicazione http://www.greatads.it info@greatads.it

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(Jerusalem-Harvard Lectures 1990)


The Role of Experiment in the Process of Learning Physics

Alicja Wojtyna-Jodko, The (Polish) Association of Teachers of Natural Sciences and Technology (SNPPI T)

1. Introduction

1.1. Educational Policy Of The European Union

- **March 2000 Lisbon European Council Declaration:**
  
  "The collective intention for Europe is to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion".

- **December 2008 European Commission communicated:**
  
  "An updated strategic framework for European cooperation in education and training".

- **2009 The European Year of Creativity and Innovation**

- **General trends:**
  - Ageing of societies – new jobs to assure both high standards of living and high standards of social care,
  - Climate change – new jobs to create a low carbon economy,
  - Development of ICT and nanotechnologies,
  - Increasing number of institutions in education and training sector.

- **Key competences and skills needed:**
  - Communication in the mother tongue and in foreign languages,
  - Digital competences,
  - Cultural awareness,
  - Sense of initiative and entrepreneurship,
  - Competence in math, science and technology,
  - Learning-to-learn skills,
  - Ability and willingness to keep learning new and specific skills for developing jobs (lifelong learning).

**UPGRADING AND UPDATING SKILLS ARE NOT JUST LUXURY FOR HIGHECH PROFESSIONALS BUT IT IS A NEED FOR ALL.**

1.2 The State Of Affairs

- **Declarative education applied in Poland** prepares our young generation more for life in an authoritarian than a democratic country.

- **In the European Union** countries with a long democratic tradition based on a market economy the educational system prepares the young generation to:
  - be able to assure economic status for themselves and their families by using their knowledge, initiative and entrepreneurship,
  - being conscious citizens of a democratic state,
- continue personal development of themselves and stimulate intellectual development of their children.

- The educational system is focused on pupils’ learning process with the guidance of teachers. Stress is put on:
  - Higher order thinking skills such as:
    - Cognitive skills: analysis, synthesis, evaluation, problem solving, decision making,
    - Personal skills: creativity, initiative, entrepreneurship, perseverance, ingenuity, acting safely with respect to oneself and others, co-operation, leadership,
    - Communicative skills: written, graphical, tabular, symbolic presentation, oral responses to larger groups,
    - Social value: decision making in a social, environmental, economic or political context with a sound justification,
    - Self-evaluation, assessment.
  - Basic competences such as:

<table>
<thead>
<tr>
<th>KNOW</th>
<th>NOW</th>
<th>HOW</th>
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<tr>
<td>KNOW</td>
<td>KNOW</td>
<td>KNOW</td>
</tr>
<tr>
<td>Mastering a complex reality</td>
<td>Investigating possible paths of research</td>
<td>Structuring the results, validating them, presenting in a synthetic view</td>
</tr>
<tr>
<td>Outlining the problem to solve</td>
<td>Comparing the various paths identified in the previous step, refining the criteria and selecting according to those criteria</td>
<td>Collecting information by experimental research, observation and measurement</td>
</tr>
<tr>
<td>Identifying cues and paths pertaining to the actual problem</td>
<td>Collecting information by research in the proper sources and by referring to resource persons</td>
<td>Summarizing and organizing information in a shape that helps understanding and communicating it</td>
</tr>
<tr>
<td>Collecting information by experimental research, observation and measurement</td>
<td>Collecting information by research in the proper sources and by referring to resource persons</td>
<td>Questioning the results of a search, building up a synthetic view, developing new knowledge</td>
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"SOCLES DE COMPETENCES: Eveil Initiation Scientifique", Ministère de la Communauté française, Administration générale de l’Enseignement et de la Recherche scientifique (B)

To prepare the young generation to be able to act successfully in a knowledge based European society with demands pointed above in the teaching/learning process more stress should be put on activating pupils initiatives in learning science (including physics). This goal can be achieved by implementing more projects and competitions into organization of the pupils’ learning process guided by teachers at all levels of education at school as well as in out-of-school activities within co-operation between schools, universities, industry and other institutions and organizations.
The better teachers universities educate the better developed students leave schools and enter universities.

A STATE RECRUITING TEACHERS POLICY

Innovative and creative pupils can be well educated by innovative and creative teachers.
If during formal schooling a teacher doesn’t refer to, makes corrections of and develops lay-ideas existing in pupils’ minds due to informal education, as the result of the school teaching process two separate structures of knowledge are being created in pupils’ minds: a structure of knowledge based on lay-ideas, which is often incorrect but this structure is used in everyday life outside school, and a structured school knowledge, used only at school. This is the reason why sometimes we observe youngsters (good pupils at school) behaving outside school in such a way as if they haven’t learned at school anything concerning in, and don’t have any preparation to stimulate intellectual progress of young generation, and they don’t take any responsibility of incorrect lay-ideas created in children’s minds as the result of their activities.

Though media people and computer games creators are educated enough to be aware of their influence on children’s minds, reasoning and acting but most often they don’t want to take any responsibility for that.
1.3. Observations

- The intellectual development of a person starts in early childhood. Parents are the first teachers, they give intellectual impulses to their child and stimulate development of its mind by explaining the surrounding world and using properly chosen games to play.
- Too often parents and families don’t create enough space for their child to learn through its own mistakes, conclude and find a better solution.
- Increasing awareness of parents of their influence on the emotional and intellectual development of their child in early childhood is needed.
- **LIFELONG LEARNING starts at the moment of BIRTH** and lasts till the END OF LIFE.
- In Poland the number of primary school pupils with learning difficulties permanently increases.
- Ability to learn of many of those pupils depends on their emotional state and both change with time.
2. Pilot Activities

2.1. A Case Study

Primary school pupils at the age of 9 had difficulties in learning due to emotional problems connected with their families.

The teacher concentrated her activities on two aspects:
- arrangements of the process of pupils’ learning with a focus on physics experiments,
- co-operation with parents to solve the pupils’ emotional problems.

In two years time those pupils overcome their learning difficulties and acquired very good results at school.

At the age of 9 children like doing physics experiments and associate them more with playing than with formal school activities.

Successful manipulating with physics experiments leads to scientific awakening and increases self-confidence of children. It helps to overcome their difficulties in learning.

In Polish primary schools science problems are taught from the very beginning (6/7 – 12 years olds) but not many children enough choose science in their further education at the level of gymnasium (13 – 16 years olds).

2.2. Open Lectures

SNPPiT in co-operation with the Institute of Pedagogy of UKW (IPUKW) organized a series of open lectures for parents, grandparents and educators on „MY KNOWLEDGE HELPS ME IN GUIDING THE CORRECT DEVELOPMENT OF MY CHILD”.

A HANDS-ON & MINDS-ON portable physics experiments exhibition, created and demonstrated by SNPPiT, associated those lectures to present to adults some possible activities for awakening children/pupils’ scientific reasoning. All activities were run on voluntary basis.

PROGRAM


1. “The rôle of parents and educators in developing cognitive abilities of a child”,
2. “Why are some children rejected by their classmates?”,
3. “Disturbances in behaviour of the young generation”,
4. “The styles of grandparenthood”,
5. “About the need and inability to sameness forming in the Proteus epoch”,

(2008/2009, venue: City Hall of the City of Bydgoszcz)

1. “Supporting family activities of the City Social Centre”,
   Ewa TAPER, vice-director of the City Social Centre

Subtitle of the series: „Children ask adults difficult questions”

The lecturers represented different institutes of the Kazimierz Wielki University in Bydgoszcz.

2. “Magic of crystals”, the Institute of Physics UKW
3. “Polyurethane resins in the 21st century”, the Institute of Technology UKW
4. “Should we build the LOWER VISTULA CASCADE?”, the Institute of Geography UKW.

WCPE 2012, Istanbul, Turkey
2.3. Activities For Pupils

2.3.1 A Physics Experiment Competition (KEF)

To increase pupils’ interest in learning physics and stimulate their initiative, creativity and innovation through individual and successful manipulating with physics experiments SNPPiT in co-operation with the Institute of Physics of the Kazimierz Wielki University (IFUKW) in Bydgoszcz created a Physics Experiment Competition (Konkurs na Eksperyment Fizyczny, KEF) for primary school pupils in the school year 2008/2009.

Aiming in activating pupils in experimenting a HANDS-ON & MINDS-ON exhibition for pupils at the age of 10-12 was organized by SNPPiT in few primary schools in Bydgoszcz prior to announcement of the rules of KEF competition. As a result few groups of pupils at the age of 12 created their own physics experiments and demonstrated them in front of a jury at the Primary School nr 2 in April 2009. The jury consisted of SNPPiT representatives, an academician and students of IFUKW, the school director and the science teacher. As a prize pupils received educational materials, CERN COURIERS, a possibility to present their experiments to other pupils during a Physics Picnic in May and a visit to the scientific physics laboratory - both at IFUKW.

Four editions of KEF for primary and secondary schools pupils have been organized in the years 2008 - 2012.

2.3.2. A Seminar for Young Experimenters (SEMEK)

Since during the 1st KEF competition the pupils’ presentations were well done it was decided to create next school year (2009/2010) at IFUKW a Seminar for Young Experimenters (Seminarium dla Młodych Eksperymentatorów, SEMEK) for all pupils participating in the KEF competition to give them a possibility for further involvement in physics for developing their better understanding.

During the three editions of SEMEK (2009 - 2012) prof. Joseph Depireux (IoP ULg, B), academicians and doctor students of IFUKW and SNPPiT representatives presented to pupils of few primary and secondary schools as well as to some of their teachers such topics as: Water, Air, Light, Electricity, Magnetism, Heat, Mechanics, Nanotechnology, Physics of a human body, Physics in sports, Aerodynamics, Oscillations and Waves, Semiconductors, Material Science.

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<td>pupils</td>
<td>9</td>
<td>8</td>
<td>48</td>
<td>16</td>
<td>31</td>
<td>11</td>
<td>42</td>
<td>100</td>
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<tr>
<td>including girls</td>
<td>4 (44,4%)</td>
<td>2 (25%)</td>
<td>22 (45,8%)</td>
<td>6 (37,5%)</td>
<td>11 (35,5%)</td>
<td>2 (18,2%)</td>
<td>17 (40,5%)</td>
<td>49</td>
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<tr>
<td>teachers involved</td>
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<tr>
<td>primary schools</td>
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<td>1</td>
<td>5</td>
<td>2</td>
<td>4</td>
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<td>4</td>
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<td>lower secondary schools</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4</td>
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<td>4</td>
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<td>upper secondary schools</td>
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In the 1st edition of KEF 9 pupils took part, including 5 boys and 4 girls.

In four editions of KEF competition participated 100 pupils, including 51 boys and 49 girls. Among them 68 pupils got involved only once in KEF competition and 26 of them participated in the 4th edition 2011/2012, including 15 girls.
Half of KEF participants (50 pupils) presented their experiments during 3 editions of the Physics Picnic (once or more times).

In three editions of SEMEK seminars participated 21 pupils, including 15 boys and 6 girls. Few of them continue attending SEMEK seminars since its beginning.

2.3.3. Experymentarium

From March to June 2012 in co-operation with SNPPiT a temporary HANDS-ON & MINDS-ON exhibition was created in EXPERYMENTARIUM at IFUKW, where physics experimental sets based on everyday life and simple physics laboratory equipment were presented to school classes. Portable experimental sets, created by SNPPiT were installed there and some other sets have been bought and created by IFUKW. A group of 7 physics students (6 girls and 1 boy), an young IFUKW female employee and a doctor student, Pawel Popielarski, were involved in preparing demonstrations of physics experiments for the public to be presented during the Physics Picnic in May 2012. Posters created by the students and descriptions of the presentations written by the young employee, the doctor student and some of the pupils, participating in the KEF competition, have been published in the SNPPiT Information Bulletin „Science and Technology at School” (Nr 51, June 2012).

KEF, SEMEK and EXPERYMENTARIUM activities were run on voluntary basis.
2.4. Some Difficult Physics Concepts To Be Introduced Through Physics Experiments As Early As Possible (at the age of 9)

2.4.1. The Weather Chart

- **phenomena:**
  - **astronomy:** movement of the Earth and the Moon used for measuring time (day and night, year, month, seasons of a year);
  - **atmosphere:** wind, clouds, precipitations;
  - the atomic clock near Frankfurt, radio waves controlled clocks.

![The Weather Chart](image)

**Figure 5.**

- **measurements of parameters**
  - **temperature:** two scales, units, introduction to the relativity concept understanding;
  - **pressure:** two scales, units, introduction to the relativity concept understanding;
  - **humidity:** a while after some ice pieces have been put into a glass children touch the external wall of the glass and try to find the source of the water.
One day children started collecting data reading the values of temperature (inside and outside) in the Celsius scale, the next day they started with the Fahrenheit scale.

The result was that children started reading data with determining the unit (°C or °F) first and then reading values.

Figure 6.

With this simple experimental set we can make children familiar also with such concepts (without naming them) as:

- thermal conductivity: we put into the glass with ice two thermometers (a wooden and an aluminium one), both indicate the same temperature. Touching the bodies of each thermometer children feel a difference.

- fluctuations: mentioned above two thermometers are localized in the glass with ice in such a way that each of them indicates a different value of temperature.

2.4.2. Skin Of Water Experiments

Suggestions for activities leading to the scientific awakening of children and pupils

Figure 7. Capillary ascension (pupils observe and comment)

Figure 8. Small grains over a surface (pupils propose hypothesis)

PLAYING WITH BUBBLES

A CD container with water and some detergent as a cell of “Hele-Shaw” to conduct research on the behaviour of bubbles in a foam.
A set of shapes to demonstrate the properties of soap films, made out of soldered copper wire, is comprised of: a circle, a triangle and a rectangle, a tetrahedron, a prism with a triangular base, a cube and others.

Pupils make manipulations, observe, describe, find differences and propose hypothesis

Figure 9.

These experiments have been developed by GRASP, ULg, B,

2.4.3. **Velocity As A Vector Quantity**

- observations of moving objects and experimenting with them,
- oral descriptions,
- use of an arrow to present direction and to compare velocities.

Figure 10.
2.4.4. The Lines Of Field Forces

These two magnets shift smoothly one against the other in one direction but jump step by step in a „quantum“ way shifted in the perpendicular direction.

3. Conclusions

1. At the very first stage of formal schooling when children don‘t have yet any negative experiences in learning science (physics), successful manipulating with physics experiments based on everyday life equipment can be used to help overcoming pupils‘ learning difficulties.

2. Difficult concepts can be experimentally introduced to the children’s structure of lay-ideas without naming them and without formal definitions as early as possible. In further learning process understanding of these concepts will develop in many different aspects and circumstances.

3. A Physics Experiment Competition (KEF) in which innovative concepts, approaches and the way of presentation is taken into an account by a jury is a good way for stimulating youngsters initiative, innovation and creativity in physics experimentation at all levels of education (primary, secondary and tertiary). These pupils who attended Seminar for Young Experimenters (SEMEK) created and presented more advanced and sophisticated experiments in the next KEF competition.
4. Involvement of the university physics students on voluntary basis in preparing physics experiments descriptions (posters) and demonstrations for primary and secondary school pupils helped the students in deeper understanding of physics phenomena and in acquiring very good results at the end of the semester.

5. One of the possible long term result is that more pupils get interested and choose physics as the final exam subject at the end of their upper secondary school and more of them decide to study physics.

4. Acknowledgements

This presentation is the result of many years of my co-operation with prof. Joseph DEPIREUX within:

- EPS: Advisory Committee on Physics Education of the European Physical Society
- GIREP: International Research Group on Physics Teaching
- ATEE: Association for Teacher Education in Europe.
Practical Activities in Astronomy for Primary School Teachers Education

Lucília Maria Pessoa Tavares Dos Santos, Physics Department and Research Centre for Didactics and Technology in Teacher Education, University of Aveiro, Aveiro, Portugal, lucilia.santos@ua.pt

Cristina Maria Sá, Agrupamento de Escolas do Castelo da Maia, Maia, Portugal, fsa.cristina@gmail.com

Abstract

Astronomy studies on in-service teacher’s practices are scarce. Yet, their significant increase, in recent years, denotes the importance of this area which also has a great impact in the scientific literacy of citizens. There is a need to disseminate knowledge on this subject to overcome difficulties such as the prevalence of common alternative conceptions and the ways to do practical activities in primary school.

In this context, a quasi-experimental design was implemented with teachers from 9 schools of the north coast of Portugal with a sample of 21 teachers in the experimental group and 21 in the control group. The intention was to check if the conceptions, held by teachers, were in accordance with those described in the literature and if the professional development, based on practical activities, designed with accessible materials and suitable to put on practice with children, was the response to improve their scientific knowledge and practice. While the analysis of data from a pretest revealed alternative concepts according with literature, the average gain value of 0,23 from the pos posttest, administrated one year later, to the experimental group and the average gain value 0,11 from the control group showed that 21 in-service teachers, from the experimental group, had a significant improvement on scientific knowledge and a conceptual change due to the professional development action implemented. The effective practice of hands-on activities seems to be a proper way to build and/or strengthen the scientific knowledge of teachers, about unreachable phenomena. The results obtained are similar with several studies.

Keywords: Astronomy, practical activities, professional development, primary school

Introduction

Astronomy is present in the basic education curriculum in Portugal.

The interest and motivation that awakens in students constitute a challenge for teachers, not only due to the degree of abstraction in the basics of Astronomy, which easily leads to alternative conceptions since early in childhood and tends to prevail in adult life, but also by a lack of professional development in this area.

Currently it is important to focus on the dissemination of existing knowledge so that it can reach out to schools. One of the issues seems to be the educational action of teachers in practical activities of Astronomy to overcome the constraints detected by several studies.

Some studies have been conducted on this issue, mainly with students preparing to become teachers (pre-service teachers), in terms of alternative conceptions (Atwood & Atwood, 1995, 1996; Parker & Heywood, 1998; Summers & Mant, 1995), and in relation to the implementation of professional development programs (Sebastià & Torregosa, 2005; Trumper, 2003, 2006).

Also, there is a lack of professional development based on activities designed to empower primary school teachers to improve their knowledge in the field of Astronomy or to acquire practical skills in the area. This fact is an obstacle that prevents teachers to tackle the problem of non-effective learning process in an intellectually comfortable way, and consequently the option is often to approach the curricular contents over-using and miss-using computer simulations, not because they are facilitators, but to avoid the scientific explanation by emphasizing the entertaining aspect. Practical activities are not considered an alternative due to the same scientific difficulties.
Lelliot & Rollnick (2010) analyzed 103 publications, between 1974 and 2008, of which 95 were published after the decade of 90. Most articles have gathered data on students in schools, while 21 studies have focused on teachers and 7 were based in museums and science centers. As for themes or topics met the following articles: 36.8% on the conceptions of the Earth; 34.9% on the Sun-Earth-Moon system; 33.9% on the day and night cycle; 26% on the seasons; 24% over gravity; 13.5% on the Sun and the stars; 12.6% on the solar system; 8.7 about size and scale; 6.7% other.

For these researchers, topics which present conceptual difficulties as the seasons and the phases of the Moon, although they have been extensively studied, the impact of their results does not reach up to the teachers and the schools.

One of the ways for the development of understanding of astronomical phenomena seems to be the professional development and educational courses based on practical activities (Trumper, 2003, 2006; Trundle et al, 2006, 2007; Bell & Trundle, 2008; Langhi, 2011).

Based on these assumptions, a continued education action relevant for professional development and promotion, in practical Astronomy activities, oriented to Primary School Teachers was elaborated and implemented. The focus was put on the curricular contents for Primary School: Sun-Earth-Moon system; day and night cycle; Moon phases; seasons of the year; science and technology.

With this 25h action we tried to answer the following question:
- Do the conceptual understandings of teachers agree with those described in the literature?
- Does the professional development produce significant results to help teachers overcome the difficulties in this area?

**Methods**

A quasi-experimental design was the option to search answers for the research questions. So, to achieve this purpose a professional development course was implemented with 21 primary teachers who participate as experimental group and 21 as the control group. The convenience sample, Table 1, was a set of 42 in-service teachers from 9 schools in the North coast of Portugal.

**Table 1. Participants’ characteristics**

<table>
<thead>
<tr>
<th>Teachers</th>
<th>Experimental Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 30-40</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>41-50</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>51-57</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>In-service (years)</td>
<td>5-15</td>
<td>9</td>
</tr>
<tr>
<td>16-25</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>26-35</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Note that no teacher took place in astronomy courses. Only 4 of the experimental group and 10 of the control group took action in Experimental Teaching of Sciences (professional development supported by the Ministry of Education and Science at the national level).

For data collection a questionnaire was applied in a pre-test situation, a post-test one month later and a post-posttest one year after the implementation of the activities. The tests consisted of a 15 issues adapted questionnaire (Trumper, 2006), of both closed and open answers types. The questionnaire was validated by a panel of judges consisting of three lecturers from the Department of Physics and the Department of Education of the University of Aveiro and was previously applied to 10 teachers, teaching in schools not covered by the study, which formed the pilot study.
The study began with a workshop, to validate two activities considered innovative. After analyzing the results, the action plan that included a theoretical component and a hands-on set of activities selected from the International Year of Astronomy, was adjusted to meet the particular needs identified on the sample.

The professional development action took place during 25 hours and was structured with a theoretical part in which all participants discussed the assumptions that provide the theoretical framework underpinning the practical part (astronomy activities), in accordance with the specific skills required by the primary school curriculum.

Thus, in a first part the theoretical framework raised the dialogue among all those present, and in a second part, the teachers experienced the activities in work groups. These activities were selected from a set provided during the International Year of Astronomy (http://astronomia2009.es/Astroeduca-t.html) and adapted to be applied to students of 3rd and 4th year of schooling, according to the learning objectives established, and contemplating an interdisciplinary approach between science, Portuguese language, mathematics and artistic expression.

Practical Activities

From the set of practical activities we decided to describe three related to the movement of the Earth, the Moon and the Sun-Earth-Moon system.

Activity 1 - Construction of a model of the sky with a transparent “salad bowl” on which the apparent movement of the Sun was directly registered in an outdoor activity, according to the following learning objectives:

a) The Earth rotates around its imaginary axis for a period of about 24 hours;
b) The rotation of the Earth causes the day and night cycle.

The following questions were formulated in order to trigger the activity:

i) Where is the Sun?
ii) What is the “path” of the Sun?
iii) What happens to the late afternoon Sun?
iv) What causes day and night?

After the construction of the model, the teachers, in groups of 5 elements, drew the preliminary ideas of how they think that the path of the Sun is in the sky. 3 groups predicted the path by placing the Sun at the zenith. The other 2 groups had suspended arcs without having in mind that the Sun “rises” and “sets” on the horizon.

At the same time the shadow of a small stake was registered, which allowed inferring that as the Earth undertakes the rotation motion, the shadow moves from a position closer to the West to a position closer to the East, varying its length, and that the minimum value indicates the North. At the same time, the apparent motion of the Sun, on the celestial sphere, describes a motion from a position close to East to a position close to the West, reaching its highest position when the shadow was a minimum, indicating South.

Written record of the groups:

“The shadows vary in size at different hours of the day (decreasing to half in a day). The shadow is not always in the same position, heading northwards clockwise.”

“The shadow decreases moving towards the North. While the path of the Sun moves South.” “The path forms a rising arc to the West. The shadow of the stick has an opposite trajectory and decreases. The Sun’s trajectory is opposite to the motion of the Earth.”

They may conclude that the Earth rotates in direct sense.
This activity has generated a lot of interest not only for the possibility of discussing various concepts, which allowed to get back to it throughout the professional development action, but also because the teachers confronted their initial ideas (alternative concepts) with the evidence observed (un)building and (re)building their knowledge.

Activity 2 - Learning objectives:

a) The Moon is a satellite which orbits the Earth;

b) The Moon seems to change shape, showing different stages.

In order to answer the question “why do we always see the same face of the Moon?” each group was asked to perform an Earth-Moon model, in which the “Earth” was a chair and each person representing the “Moon” had to make a translation path around the “Earth”, always looking at the chair and highlighting that, in this situation, the “Moon” had carried out a rotation about herself, at the end of the translation. On the other hand, performing the translational motion around the “Earth” while looking for a particular mark previously made on the wall, made them notice that they are not conducting a rotation motion, therefore not showing various faces to the “Earth”. The teachers came to the conclusion that the rotational and translational motion of the Moon around the Earth have the same period of time and that is why we (on Earth) always see the same face of the Moon.

It was stressed that the observation of the Moon should be encouraged for an extended period, but in the context of the action, with a limited term, a digital simulation was used on the phases of the Moon: http://www.schoolsobservatory.org.uk/astro/esm/moonphs.shtml

Another learning situation was enjoying a day of Moon Crescent phase to ask teachers if the Moon was visible during the day. Went abroad for the search and the result was unexpected because they did not count see the Moon during the day.

With a Styrofoam ball attached to a skewer with the arm slightly raised, each participant tried to position him(er)self so that they see the different phases of the Moon through the reflection of the sunlight on the ball. With this activity students were able to experience the position that the Moon should occupy in relation to the Earth and the Sun in order to make visible the different aspects of the Moon’s illuminated side.

Activity 3 – Aiming to the following learning objectives:

a) The Earth is part of the solar system;

b) The solar system includes the Sun and eight planets;

c) Earth’s nearly circular orbit, allows us to see different constellations at different times of the year.

The Stellarium software program (www.stellarium.org/) was used to provide activities to answer the questions:

i) Where are the stars during the day?

ii) Which planets are parts of the solar system?

The realization of these activities was very motivating for all teachers. The program is very intuitive, easy to use and offers many possibilities for exploration. They were asked to enter their date of birth and see in what constellation the Sun was “positioned” at the time. Everyone was able to verify that there were differences between the Zodiac sign identified, and the Zodiac sign they were used to associate with the very same date. This is important to understand the historical reason of the Zodiac signs and to understand that the Earth has other movements such as the precession of its axis around the Ecliptic axis. The scientific explanation of the Zodiac appears to have contributed to understand astrology as a pseudoscience.
Data And Findings

In order to compare the values obtained an index of gain value was used, according to Kalkan & Kiroglu (2007) and based in Zeilk, Schau & Matten (1999), so that \( g = \frac{(\text{post-test} - \text{pre-test})}{100 - \text{pre-test}} \). The gain value can vary between 0 and 1, so for 0 there is no change and for 1 there is a 100% change of the percentages from the pre-test to the post-test.

Particular attention should be paid, in this study, to the issues related with the Moon and the seasons, as they were considered difficult to understand.

The analysis of the pre-test questionnaires, applied to teachers of the experimental group, reveals the following answers:

- The Moon is not visible during the day (85% of replies);
- The Moon takes a day to rotate around its axis (50% answers);
- The Earth’s axis tilts forward and back (45% answers);
- The Sun is closer to the Earth than the Moon (30% answers).

### Table 2. Percentages and gain value for the correct answer by group

<table>
<thead>
<tr>
<th>Question</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Gain</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (% correct)</td>
<td>Post-test (% correct)</td>
<td>Post-Posttest (% correct)</td>
<td>Pre-test (% correct)</td>
</tr>
<tr>
<td>Correct answer: False</td>
<td>N=21</td>
<td>N=21</td>
<td>N=20</td>
<td>N=21</td>
</tr>
<tr>
<td>The Moon is not visible during the day, is it true or false?</td>
<td>15</td>
<td>85</td>
<td>79</td>
<td>0,76</td>
</tr>
</tbody>
</table>

When questioned if the Moon is visible during the day, Table 2, the experimental group had a gain value 0,76 and the control group 0,45.

For the question “Does the Moon rise and sets up every day?”, Table 3, only 20% of the teachers at the pre-test gave the right answer. One month later the ratio increase to 60% and one year after to 76%. In the control group, 57% of the teachers answered the right question at the pre-test and 76% at the post-test. These results suggest that the majority of the teachers were interested in the issues and sought to know the correct answers.

### Table 3. Results for the question: The Moon rises and sets up every day at the same time, is it true or false?

<table>
<thead>
<tr>
<th>Question</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Gain</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (% correct)</td>
<td>Post-test (% correct)</td>
<td>Post-Posttest (% correct)</td>
<td>Pre-test (% correct)</td>
</tr>
<tr>
<td>Correct answer: False</td>
<td>N=21</td>
<td>N=21</td>
<td>N=20</td>
<td>N=21</td>
</tr>
<tr>
<td>The Moon rises and sets up every day at the same time, is it true or false?</td>
<td>20</td>
<td>60</td>
<td>76</td>
<td>0,70</td>
</tr>
</tbody>
</table>
When questioned about the reason why we always see the same face of the Moon, Table 4, the answer considered correct corresponds to a gain of 0.20 for the experimental group similar with the value 0.17 achieved by Kalkan & Kiroglu (2007). The control group obtained 0.05 which leads to thinking that this area is difficult to understand.

**Table 4. Results for the question: Why we see the same side of the Moon?**

<table>
<thead>
<tr>
<th>Question</th>
<th>Experimental Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (% correct)</td>
<td>N=21</td>
</tr>
<tr>
<td>Why we see the same side of the Moon?</td>
<td>50</td>
<td>60</td>
</tr>
</tbody>
</table>

The answer to this question, on the table 5, shows the difficulty of teachers in understanding the dynamics of the Sun-Earth-Moon system in the phases of the Moon, as the gain value for the experimental group was 0.19 and 0.11 for the control group.

**Table 5. Results to the question: Draw the Sun, Earth and Moon so that the Moon can be seen from Earth in first quarter phase.**

<table>
<thead>
<tr>
<th>Question</th>
<th>Experimental Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (% correct)</td>
<td>N=21</td>
</tr>
<tr>
<td>Draw the Sun, Earth and Moon so that the Moon can be seen from Earth in first quarter phase.</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

When questioned about the reason why the Earth is warmer in the summer than in the winter, Table 6, some teachers expressed an alternative conception - “the cause is the proximity of the Earth relative to the Sun” also verified by Mant and Summers (1995) with a value of 14.29 and by Trumper (2001) with a gain value of 0.20. In the pre-test, 45% responded it was due “to the inclination of its axis back and forth”, that matches 0.31 in Trumper’s study (2001).

**Table 6. Results of the question: Why the Earth is warmer in the summer than in winter?**

<table>
<thead>
<tr>
<th>Question</th>
<th>Experimental Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test (% correct)</td>
<td>N=21</td>
</tr>
<tr>
<td>Why the Earth is warmer in the summer than in winter?</td>
<td>30</td>
<td>75</td>
</tr>
</tbody>
</table>
Discussion and Conclusions

We note, as well as Trumper (2001, 2003, 2006), that the teachers have concepts related to the Sun-Earth-Moon system, their motions, causes and effects that are not in accordance with the currently accepted scientific concept. The pre-test data analysis revealed that teachers had alternative conceptions similar to those described in literature. Post-test results revealed a significant improvement in the knowledge of some of the scientific contents and a conceptual change.

A main conclusion was drawn: the effective practice of the hands-on activities that were designed for the students revealed to be a proper way to build and/or strengthen scientific knowledge of the teachers, about irreproducible phenomena. The same activities, addressing the same scientific contents, need only to have alternative designs for students and for teachers. The results obtained are in accordance with several studies: Trumper (2006), Kalkan (2007) and Frede (2008).

Therefore, continued education of teachers, as well as the dissemination of good practices and materials seems to be an effective option to improve the teaching and learning of basic concepts in Astronomy.

References


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**Appendix**

<table>
<thead>
<tr>
<th>Question</th>
<th>Experimental Group</th>
<th>Control Group</th>
<th>Gain&lt;br&gt;&lt;sup&gt;*&lt;/sup&gt; &lt;br&gt;N=21</th>
<th>Gain&lt;br&gt;&lt;sup&gt;*&lt;/sup&gt; &lt;br&gt;N=21</th>
</tr>
</thead>
<tbody>
<tr>
<td>The order of the phases of the Moon is...</td>
<td>75 85 70 -0,20</td>
<td>71 71 -0,03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Moon rises and sets up every day at the same time, it is true or false?</td>
<td>20 60 76 0,70</td>
<td>57 76 0,45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Moon is not visible during the day, is true or false?</td>
<td>15 85 79 0,76</td>
<td>57 76 0,45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Moon during the full moon rises around 6 p.m., is true or false?</td>
<td>50 60 85 0,70</td>
<td>57 53 -0,10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imagine the full Moon rising in the East. What is the image of the Moon passed six hours?</td>
<td>40 85 35 -0,08</td>
<td>19 47 0,35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why we see the same side of the Moon?</td>
<td>50 65 60 0,20</td>
<td>38 41 0,05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draw the Sun, Earth and Moon so that the Moon can be seen from Earth in first quarter phase.</td>
<td>20 25 35 0,19</td>
<td>14 24 0,11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With reference to the Earth, enter the correct sequence for (Sun, Moon, Pluto, other stars) extends from closer to the farthest.</td>
<td>25 85 45 0,27</td>
<td>33 24 -0,15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explain the origin of night and day.</td>
<td>0 5 0 0,00</td>
<td>0 0 0,00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why the Earth is warmer in the summer than in winter?</td>
<td>30 75 40 0,14</td>
<td>38 41 0,05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On September 22 we see the sunset to the West. Passed 2 weeks the Sun seems to be more to the North, the South, or in the same place?</td>
<td>40 75 45 0,08</td>
<td>14 24 0,11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the Zodiac?</td>
<td>20 85 40 0,25</td>
<td>24 35 0,15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Sun is positioned in the constellation Gemini. What is the constellation in which sits the Sun at sunset?</td>
<td>5 25 5 0,00</td>
<td>0 0 0,00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using Action Research to Improve Teaching of Electricity for Primary Science Physics

Soleh Mohd Noor, Lutong Primary School, Miri, Sarawak, MALAYSIA
Siti Hendon Sheikh Abdullah, Science Department, Technical Teacher Training Institute, MALAYSIA

Abstract

Student teachers in the Teachers Training Institute in Malaysia are trained to become primary school science teachers. Training of the science teachers emphasises on the Science teachings as a whole, but not much emphasis have been given to the teaching of physics. Student teachers were often faced with problems to deliver physics concepts, prepare teaching materials and select approaches to teach physics in their primary science classes. One concept that has always contributed problems to most student teachers is electricity. A student teacher realised that he was not able to conduct experimental class because was he was unable to prepare appropriate materials. His Year 5 pupils do not recognise electrical components symbols and were unable to prepare basic circuits from the circuit diagrams given in the science textbook. Based on his reflections, he developed an action plan which was; to use symbol model, prepare a Simple Circuit Kit for pupils to conduct experiment, and use analogy to discuss series and parallel circuits. These actions were implemented during his internship at a school in Kuala Lumpur. From observations, pupils were able to connect the circuits and gained the necessary skills needed for experimenting. They were more interested in the lesson, draw conclusions and answer questions related to the experiment. The pupils responded to a questionnaire that they could conduct experiments easily with the help of the Simple Circuit Kit. A paper and pencil test administered shows that pupils understood the electric concepts and could answer most of the questions given. The outcome of this research shows that teachers could improve their teaching by reflecting on their problems, plan and take actions to overcome the problem. These actions could lead to innovative measures to prepare materials that could help teachers overcome problems related to their teachings.

Keywords: action research, primary school physics, students teachers, electric kit

Introduction

Physics in the primary school curriculum in Malaysia is part of the primary Science curriculum. The primary curriculum is divided into two levels, which are level 1 and level 2. The level 1 curriculum is for Year 1, 2 and 3 pupils while level 2 curriculum is for Year 4, 5 and 6 pupils. Under the Integrated Primary School Curriculum or Kurikulum Baru Sekolah Rendah (KBSR), physics at level one is integrated into the Science curriculum under the theme Learning About the World Around Us which includes the topic light, measurements, electricity, pushing and pulling and spring. At level 2, the topics are themed under Investigating Force and Energy, Investigating Materials dan Investigating Technology for the topics measurements, energy, electricity, light, heat, strength and stability and machine. The Malaysian education system is currently undergoing a curriculum transformation where the new curricula was renamed Standard Primary School Curriculum or Kurikulum Standard Sekolah Rendah (KSSR) which began in Januari 2011 for Year 1 pupils. Currently, KSSR is implemented for Year 1 and Year 2 at all primary schools in Malaysia. Under the new curricula, science is taught as the subject The World of Science and Technology and themed into Physical Science and Technology in Sustainable Living where teachings aimed to create interests in science, develop creativity through experiences to gain the science knowledge through mastery of science knowledge, scientific and thinking skills and scientific attitude and moral values (Ministry of Education, 2010). The physics concepts are themed under Physical Science (shape and sizes, seeing, float and sink for Year 1, and light and shadow for Year 2).

At the Teacher Teaching Institute in Malaysia, student teachers are trained to become primary school science teachers and were taught physics as one part of the primary science teacher training curriculum. Thus they are non-major physics teachers. As the training given at the institute emphasise on Science teachings as a whole, not much emphasis has been given specially for the teachings of physics concepts, or to help student teachers’ overcome their difficulties when delivering these concepts. Teachers need to fully understand the physics concepts before delivering them to their pupils, but the problems persists not only among the non-major primary school teachers but also non-major physics teachers in the secondary school (Khalijah & Siti Hendon 2006; Siti Hendon 2008).
The Problem

Physics has always been a branch of science that school children claimed to be difficult and not relevant to their lives. Students’ interest in physics declined when they reach a higher level (Williams et.al 2003). Thus it is essential that these concepts were delivered properly from the lowest level to prevent the difficulties persisting to a higher level physics. Thus primary physics concept must be taught in such a way that pupils have good understanding of the concepts through the proper teaching and learning approaches which could aid the understanding of physics through creativity, interest and motivation. It is essential that when the students learn physics at a higher level, the new concept does not conflict or create a cognitive conflict with their existing knowledge (Osbourne, 1983).

A research on upper secondary Malaysian students’ difficulties in physics showed that students claimed the topics light, electricity, electromagnetism and electronics are the most difficult concepts in physics (Siti Hendon, 2008). Teachers using inappropriate teaching and learning materials which are not suitable to the pupils’ level will lead to pupils having difficulty to understand the concepts especially when they were unable to produce results from the experiments conducted. This situation leads to pupils giving up on the experiments, lost motivation and interested to do further investigations. Furthermore, inaccurate experimental results could affect pupils understanding of a concept, thus leading to misconceptions (Ndirangu & Mungai, 2003).

Method

Action Research

The problem

As student teacher from the teaching institute, I realised that I was not able to conduct an experimental class for electricity smoothly due to several problems faced during my past three sessions of practicum. As part of the requirements for me to complete my Bachelor of Teaching degree program was to conduct an action research, I decided to solve this problem in planned manner through action research. An action was conducted based on the Lewin (1946) and Laidlaw (1992) model where action researchers identify an aspect of the educational practice to improve, plan an action, implement the action, collect the data and continuously reflect on the actions taken(before, during and after the action) and take further actions by developing a second cycle of action research.

The reflection

Upon reflecting on my problems in the teaching electricity, I realised that the main contributor to the problem was my inability to prepare appropriate materials for experimental classes. The conventional materials I gathered from the science room could not help my pupils to produce proper circuits for their experiments. I also realised that pupils could not recognise the electric components symbols and were unable to prepare a circuit based on a circuit diagram given from science textbook. I depended on the textbook and my lack of creativity to produce materials for my lab classes lead to pupils having more difficulties and could not produce results from the experiments. They were unable to connect circuits properly. Pupils also could not visualise the current flow in a simple, series and parallel circuit.

The action plan

Based on my reflections of the problems, an action plan was developed to overcome them which were to; use symbol model to refresh pupils on the electric components symbols, prepare an electric kit for pupils to conduct experiment on circuits and use analogy to discuss current flow in a series and parallel circuit. I prepared a symbol model so that my pupils are constantly reminded the meaning of each component given as symbols in the circuit diagram.

The next step was to prepare an electric kit that could assist pupils to do the experiment. The electric kit, Simple Circuit Kit was developed based on my analysis of the pupil’s problems gathered from observing them doing experiments and evaluation with a paper and pencil test. The Simple Electric Kit was developed by focusing on a theme and present pupils with a series of scaffold experiences that illustrate key concepts, contents and principles (Rios, 2005). It is also to help pupils experiment so that they can understand the science content and master the scientific skills when doing experiments. The kit consisted of light bulbs, switches, batteries and battery holders and connecting wires. The kit considered easily available materials
like mounting board and multipurpose adhesive to replace circuit board and their accessories. These are easily available materials that can be obtained and replaced by teacher or pupils when they use it in their classes. This selection of materials was to give ideas to the pupils that science experiments need not use expensive sophisticated materials, but could be easily conducted using readily available materials from around them (Siti Hendon & Khalijah, 2007). The Simple Circuit Kit comes together with a User Guide so that pupils could utilise it quickly and easily.

The third plan was to use analogy to explain the flow of current in a circuit. The role of a switch in a circuit is analogized to a hanging bridge. I explained that when the bridge is removed, no cars could pass through it, but cars can pass through it when it is lowered or connected. Similarly, current could not pass through circuit when the switch is off.

In series circuit, when any switch is opened light bulb will not light because there is no current flowing in the circuit. This circuit is analogised to a with one-way street that has several bridges that opens, and then the car cannot be through these bridges. This comparison made to compare to electricity cannot flow, then the bulb will not light up.

In parallel circuit, when any switch is opened one light bulb in the circuit still light up because there is a current that can flow in the circuit. This circuit can be compared to a road with many lanes, if one-lane bridge is open, then the car cannot be through the alley, but in cars will be able to pass through the road by the other lanes. Electricity was still able to flow and the bulb will light up if one switch is closed. So when all the switches are closed the bulb will not light up.

The action

I implemented the actions in my science class when I came to school for final semester internship. I began to teach the topic Electricity for Year 5 pupils by helping them identify the symbols of various components in an electric circuit. Using the Simple Electric Kit the pupils experimented on circuit diagrams and identify the differences in the arrangement of bulbs in a series and parallel circuits, observed and compared the brightness of the bulbs in series circuits, parallel circuits, between series and parallel circuits and carry out activities and compare what happen to the bulbs in a series circuit and a parallel circuit when various switches in each circuit are off.

Data and findings

Three forms of data collections methods were used in the study, which were observation checklist, survey questionnaire and achievement test. The findings of this action research proved that I have improved on my ability to conduct an experimental class on the topic electricity. My observations of the pupils were recorded in the observation checklist in Table 1.

Table 1. Observation checklist on pupils while using the Simple Electric Kit

<table>
<thead>
<tr>
<th>Pupils’ behavior</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Kit</td>
</tr>
<tr>
<td>Able to manipulate materials given</td>
<td>/</td>
</tr>
<tr>
<td>Able to communicate well</td>
<td>/</td>
</tr>
<tr>
<td>Produce results from experiment</td>
<td>/</td>
</tr>
<tr>
<td>Actively involved in the activities given</td>
<td>/</td>
</tr>
<tr>
<td>Use materials correctly</td>
<td>/</td>
</tr>
<tr>
<td>Able to connect series circuit correctly</td>
<td>/</td>
</tr>
<tr>
<td>Able to connect parallel circuit correctly</td>
<td>/</td>
</tr>
<tr>
<td>Able to answer questions related to the activity</td>
<td>/</td>
</tr>
<tr>
<td>Interested in the activity</td>
<td>/</td>
</tr>
<tr>
<td>Able to make conclusions from the activities</td>
<td>/</td>
</tr>
</tbody>
</table>

WCPE 2012, Istanbul, Turkey
Table 1 shows pupils’ behaviour observed while using the kit. Pupils were able to prepare series and parallel correctly while using the Simple Circuit Kit, thus getting the correct data which enable them to make conclusions and answer relevant questions related to it. The analysis of the pupils’ behaviour indicates that a well prepared teaching kit could develop interest and aids pupils’ understanding of a concept (Dourmashkin & King, 2005).

A survey questionnaire was distributed to the pupils after experimenting to analyse their perceptions of using the Simple Electric Kit. It was also to analyse if kit is appropriate to these group of pupils (Table 2). Pupils’ responses to the questionnaire indicated that the Simple Electric Kit made it easier for pupils to experiment on electricity, save time to complete the activities and that the kit is relevant to the topic studied. Pupils responded that they preferred doing experiments using the kit compared to not using the kit previously.

Table 2. Pupils responses to survey questionnaire

<table>
<thead>
<tr>
<th>Items</th>
<th>Students who responded “Yes”, N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you done any science experiments before this?</td>
<td>26 (100)</td>
</tr>
<tr>
<td>Have any of the experiments been done using a experimental kit?</td>
<td>13 (50)</td>
</tr>
<tr>
<td>Does the Simple Electric Kit make it easier for you to do the experiments?</td>
<td>22 (84.6)</td>
</tr>
<tr>
<td>Does the Simple Electric Kit helped you save time to conduct the activities?</td>
<td>24 (92.3)</td>
</tr>
<tr>
<td>Is the Simple Electric Kit relevant to the topic learnt?</td>
<td>26 (100)</td>
</tr>
<tr>
<td>Do you prefer doing experiments using an experimental kit compared to not using an experimental kit?</td>
<td>26 (100)</td>
</tr>
<tr>
<td>Do you learn from doing experiments using the Simple Electric Kit</td>
<td>26 (100)</td>
</tr>
</tbody>
</table>

A paper and pencil test was then administered to evaluate if the Simple Electric Kit could assist pupils to have a better understanding of the electric concept thus being able to answer questions related to it. The increase in the pupils’ achievement shown in Table 3 indicated that with the kit, pupils understood the concepts better thus able to answer the given questions. Table 3 shows the comparison between the pupils achievement before and after using the Simple Electric Kit. Pupils marks were categorised as good, average and weak based on the percentages achieved in the test.

Table 3. Pupils’ achievement in the pre-test and post-test

<table>
<thead>
<tr>
<th>Achievement</th>
<th>Scores %</th>
<th>Pre test</th>
<th>Post test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency (N)</td>
<td>%</td>
<td>Frequency (N)</td>
</tr>
<tr>
<td>Good</td>
<td>80-100</td>
<td>4</td>
<td>15.3%</td>
</tr>
<tr>
<td>Average</td>
<td>40-79</td>
<td>12</td>
<td>46.1%</td>
</tr>
<tr>
<td>Weak</td>
<td>0-39</td>
<td>10</td>
<td>38.4%</td>
</tr>
</tbody>
</table>

The analysis of the pupils’ performances show that the percentage of pupils achieving good scores have increased from 15.3% (N=4) to 57.7% (N=15). This indicates that the actions taken have helped pupils to understand the electric concept thus being able to answer the given questions well. However, a total 26.9% (N=7) of the pupils are still achieved weak scores in the post test, indicating the actions taken have not worked well for all pupils. This imply that using relevant material must be supported by good pedagogical skills so that the teacher is able facilitate pupils well so that pupils can achieve optimum learning during the teaching and learning processes (Vygotsky, 1930).
The findings of this study indicated that by undertaking the actions, pupils were able to complete the experiments on time and get the relevant results from the experiments. The class went well because pupils were able connect the circuits correctly and produce results from the experiments. Thus pupils could make conclusions and answer the questions given. The increase in the pupils’ marks in the post test indicated that pupil understood the concepts. The findings of the study indicated that I have improved my ability to teach the concept electricity by taking actions such as using symbol model for electric components, prepare the Simple Circuit kit and use analogy to explain current flow in a series and parallel circuit.

**Conclusions**

The outcome of this research shows that teachers could improve their teachings of the physics in the primary school concepts by reflecting on their problems, plan and take actions to overcome the problem. These actions could lead to innovative measures to prepare teaching materials that could further aid teachers in their teachings of the primary physics concepts.


Contextual Approach for Teaching Physics to Non-Major Primary School Student Teachers

Siti Hendon Sheikh Abdullah, Science Department, Teacher Training Institute, Technical Education Campus Kuala Lumpur, MALAYSIA

Abstract

Student teachers in a teacher training institute were taught Physics in Context at the 2nd year of their degree program. The contextual approach was used as they were non-physics major students and physics is only part of the program and taught together with the other science fields. These student teachers must be equipped with the proper knowledge and skills so that they will be able to teach physics successfully in their own primary science classrooms. The teaching strategies were (1) make them ‘do’ physics, (2) explain phenomena around them using physics, (3) using simple, real life materials for PCK activities and (4) encourage innovation. Data was collected by questionnaires distributed to 2nd, 3rd and 4th year students who have experienced learning physics by the contextual approach. The finding shows that the student teachers agreed the contextual experiences gained in the physics lessons make physics more meaningful as it promoted understanding and interests, they are able to relate physics in their everyday life situations and solve physics problems. Their responses indicated that learning physics contextually aided their understanding of the physics concepts and being given constant contextual exposure helped them make sense physics, thus have better understanding and confidence to teach physics in their primary science classrooms. However, most students still preferred the typical direct and straightforward physics questions compared to contextualized questions. The finding of the study implied that student teachers who have completed this course are well equipped with physics content knowledge but we needed to be equipped with the relevant pedagogical content knowledge to teach physics.

Keywords: contextual approach, student teachers, content knowledge, pedagogical content knowledge, primary science classrooms

Introduction

The Teacher Training Institute of Malaysia offered degree courses for primary school teachers. It is a 4 years or 8 semesters program called the Program Ijazah Sarjana Muda Perguruan (PISMP) or Bachelor of Teaching Program that offered Science for Primary School courses where physics courses are part of the courses offered. These student teachers are non-physics major and were taught physics with the other science fields like biology and chemistry. Students were selected into the program based on their performances in the SPM (equivalent to O-level) examination and have to undergo 3 semesters preparatory course. Physics in Context is offered in the 3rd semester, aimed to prepare the student with the appropriate content, pedagogical and pedagogical content knowledge so that they will be able to teach at the primary school science level. It is essential that these future teachers have good content knowledge so that they fully understand the physics concepts and in turn will be able to convey the physics concepts contextually to their pupil, promoting interests and understanding to their primary school pupils. The student teachers will have four sessions of practicum in the last 4 semesters of program for them to apply what they have been trained for.

As PISMP is not a physics program, only two physics courses are offered for these future primary science teachers which are, ‘Physics in Context’ and ‘Earth and Space’. Majority of the student teachers are girls and do not have a good physics background. Their common problems were to understand, apply concepts or answer questions. As future teachers, they have to overcome these problems before they go to school to teach. Teachers who have difficulties or misconceptions will have trouble delivering these concepts, and could also transfer the misconceptions to their pupils. For example, a student teacher observed during practicum stated that gravity is ‘a form of energy’ when his year 3 pupil queried about gravity while he was teaching The Basic Needs of Plants, explaining that the roots of the plant move downwards due the pull of gravity. For a classroom situation like this, the teacher was required to give spontaneous answers to satisfy...
This page is intentionally left blank.
the pupils’ curiosity on the topic that he was teaching. The implication of giving incorrect information and ideas are that a teacher will supply pupils with the wrong ideas based his misconceptions which are transferred to a total of thirty something pupils that he is currently teaching (and more later on if it is not rectified).

By teaching physics contextually, we involve student teachers with learning experiences or linking physics to their directly to their daily lives (Rayner 2005, Stinner 1994). This leads to a meaningful learning process that triggers interests. Thus student are more proactive and go for a quest for understanding in this contextual learning process. Students get to observed various situation and phenomena around them and apply the physics that they know to explain them. Whitelegg and Parry (1999) discussed the advantages of teaching physics in context, stating that students apply previous knowledge to real life situations, and initially learn physics through analysing these situations. The contextual approach includes application and sharing of real life situations about the topic during lectures, experiment and pedagogical content knowledge activities and project work. Students were also required to search for situations or phenomena based on the topic and produce a graphic organizer of their search of the topic. To encourage and motivate students’ involvement in the T&L process, students were given marks for their initiative which will be included in the final semester results.

**Methods**

All students in the institute were taught physics contextually, but data are only collected from the classes that have taught by the same lecturer. This is to ensure the reliability of data collected as contextual approach adopted might differ from one lecturer to another. The two types of data collection method are survey questionnaires on the contextual approach used and an open ended items on the types of physics questions preferred by the students. A four scale Likert style survey questionnaire was distributed to 54 student teachers form three kohorts which are the 2nd, 3rd and 4th year student teachers from the program. The course Physics in Context was taught in the 3rd semester which in the 2nd year of the program. While this group of student has not gone out for practicum, the students teachers in the 3rd year has gone out twice during the 5th and 6th semester, and the 4th year students has gone out four times (5th, 6th, 7th and 8th semester).

The students were taught Physics in Context using various approaches such as contextual, inquiry, constructivism, Science Technology & Society and project based learning. Students were required to relate all concepts contextually for all strategies used. The physics classes consisted of lectures, experiments, pedagogical content knowledge (PCK) activities and coursework. The coursework contribute to 60% of their final marks while the remaining 40% is from examination. Three kinds of knowledge were measured in assessing the coursework, which were acquisition of knowledge, mastery of knowledge and transfer of knowledge to ensure the student teachers have reached the necessary levels of thinking and had gathered the necessary skills while learning physics.

The 2nd year student teachers were then given two types of physics content questions to answer to support the finding of the questionnaire. Type A question which are questions taken straight form a textbook and Type B questions which are the questions Type A rephrased so that it portrays context rich questions (Enghag, Guftasson, & Jonsson, 2004). These questions will give insight on the student teachers’ preferences to the types of question given. The students were required to state the preferences to the types of questions give.

**The Strategy**

As the student teachers are non-physics major, lecturers have to strategise well to create interest, understanding and motivation to learn physics. Strategies taken were; (1) to make them ‘do’ physics, (2) explain phenomena around them using physics, (3) use simple and real life materials for PCK activities and (4) encourage innovation. Making student ‘do’ physics is by involving students with activities in which students can experience the physics in their daily life or activities. For example, students are taken to the field to study projectile motion or build towers from spaghetti strands to study strength and stability.

*Proceedings of The World Conference on Physics Education 2012*
In another case, students were highlighted with phenomenal happenings around them, and made relate the phenomenon to the topic that was being taught. One example is the sensational news of the sun rising from the west on the planet Mars, as Muslims believed when the Sun rises from the west (on Earth) indicates doomsday. Using their knowledge on motions of the planets around the Earth, students related it to the retrograde motion that they studied in the physics class and argued why it was not an indication of doomsday, but explained the phenomenon using Kepler’s Laws. In the PCK activities, the future science teachers were encouraged to design activities they can use to teach physics with things that was easily available around them, based on the physics concepts learnt. Students were encouraged to use readily available material like balloons, rice cookers, laser pointers to demonstrate and discuss physics concepts. They worked collaboratively in groups to enhance the learning process through discussions and arguments. The student teachers were encouraged to innovate and produce teaching and learning materials where they applied the physics concepts that they have learnt to produce materials such as teaching aids, models or products. The physics lessons became meaningful when the students immediately applied the concepts learnt to innovate, produce materials and take part in innovation competition organized by the institute or ministry.

The four strategies were implemented in the physics classes and selected based on its usability in the topics taught. At the end of each semester, students were given a 4 point Likert Style questionnaire to find out (1) their perceptions of learning physics contextually and (2) the willingness to teach contextually when they go to school. They were also required to answer two open ended questions on learning physics by the contextual approach. The 2nd year students were then given Type A and Type B questions to answer and give response on their preferences to the types of questions.

Data and findings

As the study seek to find student teachers’ perceptions of the contextual approach incorporated in their Physics in Context classes, the data collected are find out students perception to the contextual approach from survey questionnaires. It also seeks to find if students prefer a direct textbook type questions or the types of questions which are more contextual. Two sets of similar physics problems were distributed for the students to answer and at the end of the lesson, students were given a four items open-ended questionnaire on the types of questions preferred.

Students’ responses to the Contextual Approach

A survey questionnaire consisting of 11 Likert type questions and 2 open ended items were distributed to 3 groups of students based on their cohorts. The responses are shown in Table 1 and Table 2.

Table 1. Comparisons of student teachers’ perceptions to the contextual approach

<table>
<thead>
<tr>
<th>Items</th>
<th>Students’ Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to understand concepts</td>
<td>3.84 3.44 3.58 3.61</td>
</tr>
<tr>
<td>Confident to answer questions</td>
<td>3.63 3.50 3.29 3.48</td>
</tr>
<tr>
<td>Easy to understand contextual questions</td>
<td>3.53 3.50 3.06 3.39</td>
</tr>
<tr>
<td>Easy to relate questions to experiences</td>
<td>3.79 3.61 3.65 3.69</td>
</tr>
<tr>
<td>Relevant activities</td>
<td>3.74 3.61 3.35 3.57</td>
</tr>
<tr>
<td>Activities: understand concepts</td>
<td>3.68 3.78 3.18 3.56</td>
</tr>
<tr>
<td>Activities: relate concepts to a situation</td>
<td>3.53 3.67 3.29 3.50</td>
</tr>
<tr>
<td>Search information: gain knowledge</td>
<td>3.79 3.61 3.47 3.63</td>
</tr>
<tr>
<td>Confident to teach the physics topics</td>
<td>3.74 3.44 3.12 3.44</td>
</tr>
<tr>
<td>Confident to use contextual approach when teaching</td>
<td>3.53 3.50 3.12 3.39</td>
</tr>
<tr>
<td>Will use the contextual approach when teaching</td>
<td>3.74 3.39 3.54 3.54</td>
</tr>
</tbody>
</table>
The analysis of the students’ responses indicated that that they agreed that the contextual approach has helped them understand physics concepts and gave them the confidence to answer physics questions. The activities conducted were relevant and effective to make them understand physics concepts and relate them to a given situation. The mean responses for item 3 (easy to understand contextual questions, mean= 3.39) and item 10 (confident to use the contextual approach when teaching, mean= 3.39) are the lowest. These indicate that although students agreed that the contextual approach assisted learning, they were not confident to apply concepts to answer contextual questions or use contextual approach to teach physics at the primary school. Generally, the level of response for these items declined with the time period that the student teachers have gone out for practicum, lowest for the 4th year students who have gone out to school a total of 24 weeks (mean= 3.06 and 3.12 respectively). This implies that as although using contextual approach to teach physics content is necessary for understanding, students need more help for them to be able to apply the concepts and use the same approach in their classrooms. The decline in the 3rd and 4th year students’ responses compared to the 2nd year, who have been recently taught Physics in Context shows that student teachers needs more than just content knowledge for them to be able to teach physics. Thus, necessary actions should be taken to assist them to teach the physics topics effectively so that they have the necessary pedagogical content knowledge, a knowledge usually gathered from classroom teaching experiences.

Two open-ended items were given to the 2nd year student teachers, where item 1 is ‘does learning physics contextually helps increase your understanding on the physics concepts’ and item 2, ‘does learning physics contextually helps increase your interest towards physics?’ The student teacher responses were coded and displayed into 3 themes; Contextual learning experiences, Understanding and Interests as shown in Table 2.

### Table 2. Student responses to learning physics contextually

<table>
<thead>
<tr>
<th>Theme</th>
<th>Does learning physics contextually helps increase your understanding on the physics concepts?</th>
<th>Does learning physics contextually help increase your interest towards physics?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contextual learning experiences</td>
<td>• Relate to real life • More sensitive to the things around me • Gained valuable experiences</td>
<td>• I can relate concepts to what I see in my daily life • I can explain the things that happen around me • Experiences make learning meaningful</td>
</tr>
<tr>
<td>Understanding</td>
<td>• Can see better • visualise better</td>
<td>• Easier to understand • I know what I am supposed to learn</td>
</tr>
<tr>
<td>Interests</td>
<td>• Interesting teaching</td>
<td>• Fun, I am more interested in physics</td>
</tr>
</tbody>
</table>

Students’ responded that they could understand the physics lessons better as they were able to relate physics concepts to real life and became more sensitive to things around them. They claimed that they have gained valuable experience from the physics classes. Their interests in physics increased as they were able to relate the concepts learnt to the things that happens in their daily life and explained them. Learning physics in context gave the meaningful learning of the physics topics. Some of the responses given were, ‘Yes, it helps my understanding of the physics topics taught as for every topic, we were given examples in our daily life’, or ‘Physics is something difficult. By learning it contextually, I understood why a phenomenon occurs’.

As the lessons involved every day, real life situation and activities, students claimed that it aided understanding of the physics concepts. They found it easier to understand as they could ‘see’ or ‘visualise’ better using this approach as shown in a student response, ‘It helped me to visualize what I am learning by looking at things around me’. Their interests increase when they find it easier to understand and when
they know what they were supposed to learn in each lesson. Students also claimed that they are now more interested in physics as they found the teaching approach interesting, thus had fun learning physics.

*Students’ Responses to Contextual and Non-contextual Items*

The analysis of the students’ responses in Table 3.1 shows a lower mean (3.39) for item 3 that is ‘contextual questions are easier to understand’. The 2nd year student teachers were selected to answer physics content questions followed by open ended questions to see their preferences to each type of question. The physics content questions are the Type A and Type B questions. Type A questions are physics questions extracted from a physics textbook while Type B questions are Type A questions rephrased and readjusted so that they displayed contextual situations. Table 3 shows a sample of the questions given.

<table>
<thead>
<tr>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>A car of mass 1300 kg is moving with a velocity of 105 km/h. The driver suddenly hits the brake and the car stops. The velocity of the car decreases until it stops at a distance of 53 m. (a) Calculate: (i) the deceleration of the car (ii) the value of force that acts on the car when it stops (iii) the time taken for the car to stop (b) State the forces in (i)</td>
<td>Sarah is driving her Proton Inspira car of mass 1500 kg to work. The car is moving at a velocity of 90 km/h when she suddenly see a dog crossing the street. To prevent the car hitting the dog, she quickly hits the brake until the car stops at a distance of 20 m. (a) What is the deceleration of Sarah’s car? (b) What is the value of force that causes Sarah’s car to stop? (c) How long does it takes for Sarah to stop her car State the forces acting on the car</td>
</tr>
</tbody>
</table>

*Figure 1.* Type A and Type B physics questions

The 4 items that the student teachers’ responded to are, (i) What are the differences between Type A and Type B questions? (ii) Which questions are easier to understand?, (iii) Which questions are easier to solve? and (iv) Which type of questions do you prefer during examinations? The students were requires to state reasons for each of the answers given.
Table 3. Students’ responses to physics content questions

<table>
<thead>
<tr>
<th>Students’ responses (N=19)</th>
<th>Type A</th>
<th>Type B</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference between questions</td>
<td>- brief and direct sentences</td>
<td>- Clear sentences</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>- Easier to find answers</td>
<td>- Aids visualization of situation</td>
<td>No difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Long sentence but easier to understand</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Complex sentences, too wordy</td>
<td></td>
</tr>
<tr>
<td>Easier to understand</td>
<td>12</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>- Sentences are brief</td>
<td>- Application in real life</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Questions are clear</td>
<td>- Easy to understand based on the situation given</td>
<td></td>
</tr>
<tr>
<td>Easier to solve</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>- Direct questions</td>
<td>- Related to real life</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Information can be easily extracted</td>
<td>- Can visualize the situation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Clearer</td>
<td>- Give clear information</td>
<td></td>
</tr>
<tr>
<td>Preference for examination</td>
<td>12</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>- Brief</td>
<td>- Detailed, easy to understand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Easier to understand</td>
<td>- Clear storyline</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Straight forward</td>
<td>- Questions are more specific</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Clearer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The students responses shows that a total students (N=9) could not see the differences between the two questions and claimed that the questions are the same. The remaining 10 students mostly agreed that Type A questions are brief and direct, whereas Type B questions have more sentences. Some students responded that type B questions make it easier to visualize the question, while a few claimed that the they are too wordy and complex for them to understand.

Comparing the students’ understanding of the Type A and Type B questions, 12 students found Type A questions easier to understand giving reasons that the questions are brief and clear. However, 5 students claimed Type B questions are easier to understand as it is an application of a real life situation, making it easier to understand based on the situations given. Students (N=9) also stated that who Type A questions are easier to solve because the questions are direct and they could easily extract information to answer them. On the other hand, 6 students claimed that find Type B questions easier to solve because that it relate real life, give clear information that helped them visualize better.

The analysis of the students preferences to the two types of questions indicated that both types of questions appealed students, who have different learning styles and abilities. However, most students (N=12) preferred the Type A questions during examinations, stating that they are brief, clear, straight forward and easier to understand. However, the 5 students that preferred Type B questions for examinations claimed that the questions are more detailed, have clear storyline, more specific thus easier for them to understand. The analysis indicated that most students preferred direct Type A questions during examinations due its direct and straight forward properties that allows them to easily extract information from the questions.
Discussion and Conclusions

The findings of the study indicated that non physics major student teachers responded well to the contextual approached used. Students teachers claimed that they understand concepts through real life experience (aids visualisation), could relate concepts to situations around them and willing to teach physics contextually when they go to school. The teaching and learning of physics using the contextual approach could help minimize student teachers’ misconceptions that could be transferred to pupils if not remedied. By bringing their cultures and beliefs into the physics classes, students willing to give opinions, argue and share ideas on the physics concept concerned. Teachers and lecturers need to encourage creativity and innovation so that students could apply the concepts taught into a new situation in form of teaching aids, models and products (Soleh & Siti Hendon 2011).

This study also found that even though students liked to learn physics contextually and understand contextual questions, they preferred to answer non-contextual questions during examinations. This might be contributed by the fact that the given a time frame to complete a certain amount of questions during examination is quite short, thus students do not like to spend time reading the detailed part of a question.

The findings of the study indicated using the contextual approach to tech Physics in Context has provided students teachers with the necessary content knowledge on physics. However, these inexperience teachers need assistant to deliver the knowledge effectively or use contextual approach in their classrooms during practicum or when they start teaching after graduation. The inability for teachers to deliver physics concepts properly could lead to their pupils’ loss of interest and lack of motivation to learn physics. Pupils will find physics difficult and have lots of conflicting information. Thus, the student teachers need to been given exposures on different strategies needed to teach different physics concepts so that they could improve on their pedagogical content knowledge of the physics topics. The next level of this study is to prepare relevant materials that could guide novice teachers to use the appropriate strategies and material to teach physics at the primary school level.

References


Overcoming Academic Misconceptions about the Learning and Teaching of Physics

A.P. Mazzolini, L. Mann and S. Daniel, Engineering and Science Education Research Group, Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Melbourne, Australia

Correspondence should be addressed to: Alex Mazzolini, Swinburne University, FEIS Mail Stop #38, PO Box 218 Hawthorn, Victoria, Australia, 3122 E-mail: amazzolini@swin.edu.au

Abstract

There is ample evidence that students have many misconceptions in physics, which are difficult to correct using traditional teaching methods. Even with this evidence however, many academics still use traditional teaching approaches, and seem to dismiss the evidence-based research supporting the use of active learning approaches. The research question posed in the study reported was “Why do academics teaching physics resist moving toward active learning approaches?” A meta-interpretation method was used to analyse and synthesise multiple previous studies on student learning, student misconceptions and academic teaching. The results indicated that a major factor affecting academic resistance to moving toward active learning approaches is that academics themselves have misconceptions about how effective traditional approaches are in helping students learn. The implication from this is that the same strategies for overcoming student misconceptions in physics can also be applied to overcoming academic misconceptions. The paper reports on the design of a professional development program at Swinburne University that has been initiated to address these academic misconceptions.

Introduction

Physics Education Research (PER) has initiated an important and ongoing dialog amongst many physics educators about how students learn and how teaching methods should be adapted to better engage students in the learning process. There is now a large body of PER evidence (both quantitative and qualitative) that indicates that students have many misconceptions about their understanding of physics concepts and that these misconceptions are difficult to correct using traditional teaching methods (Chu, Treagust, & Chandrasegaran, 2008; Halloun & Hestenes, 1985; Sayre & Heckler, 2008). PER has reported on many active learning techniques that appear to be much more effective than traditional methods in engaging students and in improving their conceptual understanding (Cahyadi, 2004; Crouch & Mazur, 2001; Falconer, Wyckoff, Joshua, & Sawada, 2001; Hake, 1998; Mazur, 1997a; Pollock, Chasteen, Dubson, & Perkins, 2010; Singh, 2005; Thornton & Sokoloff, 1998)

This is particularly the case in large lecture class environments (Beichner et al., 2006; Gibbs & Lucas, 1996), where traditional teaching approaches can often be described as transmissive, one-way, passive information transfer from teacher to student (characterised by the ‘sage on the stage’), in contrast to active learning approaches that can often be described as engaging, collaborative, constructivist, facilitated learning (characterised by the ‘guide on the side’).

Even with this research evidence however, many academics still use traditional teaching approaches, and seem to dismiss the evidence-based research supporting the use of active learning approaches. There are many reasons for this academic resistance; some are based around institutional barriers (such as lack of time, perceived lack of importance of good teaching in determining promotion), but some are based on more subtle academic perceptions (Mann, Chang, & Mazzolini, 2011).

To investigate this issue, the authors posed the following research question: Why do academics teaching physics resist moving toward a more active learning approach?

This paper argues that a major factor affecting this resistance to change is that academics themselves have misconceptions about how effective their own traditional approaches are in helping students learn.
To develop the argument, this paper first discusses student misconceptions and describes efforts by the authors and many others to address these misconceptions. It then presents the research method undertaken to investigate the question, that of meta-interpretation analysis (Weed, 2005) whereby the authors have analysed and synthesised the results of multiple published research studies. The findings of this analysis are then presented, offering insight into why academics resist moving toward active learning approaches. The paper then discusses the implications of these findings along with a description of a program designed to start to address academic misconceptions at Swinburne University of Technology.

**Student Misconceptions**

Education research indicates that students bring pre-existing frameworks of understanding into the classroom, and that these conceptual frameworks are built from their interpretation of subjective experiences (Redish, 1994). These conceptualisations, which can often be misconceptions, are very resistant to change, especially under traditional teaching approaches. With traditional transmissionist lecturing, students accept, often ‘literally without question’, what the teacher (authority figure) tells them, but then nevertheless reinterpret what they have been taught from within their own conceptual framework. This can be illustrated with a student quote—

*Professor Mazur, how should I answer these questions? According to what you taught us, or by the way I think about these things?*” (Mazur, 1997b). Transmissive passive instruction does little to correct student misconceptions because if the misconceptions are not challenged explicitly, there is little chance of correcting them. On the other hand, with an active learning lecture approach (such as interactive lecture demonstrations), student misconceptions are directly challenged and hence an opportunity exists to correct these student misconceptions (Nachtigall, 1990). Table 1 summarises the different characteristics of passive lectures and interactive lecture demonstrations.

**Table 1. Traditional Passive Lectures versus Interactive Lecture Demonstrations.**

<table>
<thead>
<tr>
<th>Traditional Passive Lectures</th>
<th>Interactive Lecture Demonstrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor and textbook are the source of all knowledge</td>
<td>Student guided to construct their knowledge from observation. (i.e. The actual ‘observation’ is the authority)</td>
</tr>
<tr>
<td>Students’ deeply rooted beliefs are rarely challenged</td>
<td>Students use a learning cycle to compare predictions to observations of real experiments. (<em>PODS learning cycle = Predict, Observe, Discuss, Synthesise</em>)</td>
</tr>
<tr>
<td>Students may never recognise that there is any difference between their beliefs and what they are told in the classroom</td>
<td>Students’ deeply rooted beliefs may change when confronted by differences between predictions and observations</td>
</tr>
<tr>
<td>Instructor’s role is as an authority</td>
<td>Instructor’s role is as a guide or facilitator</td>
</tr>
<tr>
<td>Collaboration with peers is discouraged</td>
<td>Collaboration with peers is encouraged</td>
</tr>
<tr>
<td>Experimental results are presented as facts</td>
<td>Experimental results are the basis on which students’ develop their understanding</td>
</tr>
</tbody>
</table>

At Swinburne University of Technology in Melbourne Australia, a group of several educators from the Engineering and Science Education Research (ESER) group (Mann & Chang, 2012) have been working for several years to identify and correct student misconceptions around electronics and electrical circuits, especially in large class environments. This research indicates that students studying complex ideas (such as operational amplifiers and electronic resonance) in an introductory electronics course have significant conceptual difficulties that are not addressed in a ‘transmissive’ instruction mode via traditional lectures, but that significant learning gains can be achieved by complementing traditional lectures with a small number of interactive lecture demonstration (ILDs) activities (A. Mazzolini, Edwards, Rachinger, Nopparatjamjomras, & Shepherd, 2011; A. P. Mazzolini, Daniel, & Edwards, 2012). The ILDs have been shown to be effective when integrated into a ‘Predict-Observe-Discuss-Synthesise’ (PODS) learning cycle (Sokoloff, 2006).
Evidence gathered over many years from these ESER educators indicates that students who have conceptual difficulties in their understanding of electronics often utilise a procedural engagement approach to their learning rather than a substantive cognitive level of engagement (Harris, 2008; Streveler, Litzinger, Miller, & Steif, 2008). The former can be characterised as a “learn-by-rote” approach, where students do the absolute minimum to conform to requirements for assessment tasks and learning activities (e.g. like handing in an assignment on time or attending a compulsory tutorial session). The latter can be characterised by students who fully engage with the tasks and activities in order to develop a deep and connected understanding of the topics they are studying (e.g. like doing some independent research in order to complete an assignment, or doing some pre-reading before going to a laboratory session).

By way of example, one of the tutors in the electronics course at Swinburne was assisting a student with an assignment. One of the questions dealt with the concept of the transient current that flow when a switch is closed in a simple resistor-inductor (RL) series circuit connected to an ideal battery, as shown in Figure 1. The tutor spent some time explaining how the RL circuit worked in general including such concepts as Faraday’s law of induction and how this law applied in an RL circuit. The student was then asked to describe how he would answer one of the questions associated with the assignment. The question required the student to determine the final current flowing in the circuit. The student simply said “I=V/R” and quickly derived the correct answer. When asked to explain his reasoning, the student said “Well, I know the voltage of the battery is 9 V and the value of the resistor is 100 Ω, so then using Ohm’s law I calculate that the current is 90 mA”. When pressed by the tutor, the student admitted that he did not know how the inductor affected the circuit, even though this was the focus of the tutor’s (one-way) explanation about how RL series circuits work!

![Figure 1. Series RL circuit.](image)

What the tutor learned from this interaction was that the student seemed to have gained little from the lecturer’s traditional instruction or from the tutor’s explanation, and that this complex conceptual idea was not clarified by either of these ‘transmissive’ modes of teaching. It appeared to the tutor, that the student was not deeply engaged and just wanted to hand in the assignment. Finding a formula that included all the numbers in the problem was sufficient, and in this instance, gave the right answer but for all the wrong reasons.

**What have we learned about correcting student misconceptions?**

*Transmissive lecturing is not particularly effective in improving students’ conceptual understanding.*

An example from the introductory electronics course taught at Swinburne can help illustrate this point. Students come into this course having already had some experience of how to interpret sinusoidal functions and the phase relationship between these functions. They learn these concepts in high school, and again in our university mathematics and electronics courses. Understanding the concepts associated with sinusoidal functions is fundamental to any understanding of AC circuits. In the electronics course, students have approximately 8 hours of traditional transmissive instruction in AC circuits followed by approximately 2 hours of active learning (interactive lecture demonstrations) aimed at reinforcing AC concepts.
Assessment instruments, in the form of multiple-choice tests that are delivered via audience polling devices (clickers), are used to test the effectiveness of the instruction in improving conceptual understanding. One of the questions in the assessment instrument specifically tests students’ understanding of phase in sinusoidal functions. This question is used before any AC instruction in our electronics course (as part of the ‘base-line test’), then after the traditional transmissive instruction (as part of the ‘pre-test’), then once again after the active learning instruction (as part of the ‘post-test’). The phase relationship between sinusoidal functions is specifically taught in both traditional and active learning instruction. The question tests whether students understand the phase relationship between the two waveforms shown in Figure 2. In this diagram, the dashed curve leads the solid curve by 90°.

Figure 2. Sinusoidal waveforms.

Table: Students with correct answer.

<table>
<thead>
<tr>
<th>Test</th>
<th>Percentage correct</th>
<th>N (excluding non-attempts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>66.7</td>
<td>81</td>
</tr>
<tr>
<td>Pre-test</td>
<td>65.4</td>
<td>52</td>
</tr>
<tr>
<td>Post-test</td>
<td>84.6</td>
<td>33</td>
</tr>
</tbody>
</table>

Figure 3 shows the number of students participating in the tests in 2011 and the percentage of these students that answered this question correctly. As can be seen, there is no improvement in interpreting the phase relationship between the sinusoidal functions shown in the graph after traditional lectures based on transmissive instruction. In fact, the detailed analysis showed that there was no significant difference in the pattern of responses for those students participating in the baseline test and the pre-test. Not only did the same proportion of students answer incorrectly, they answered incorrectly in the same way, which demonstrates that the transmissive lectures did not challenge student conceptions, or even misconceptions, about phase. On the other hand, there is considerably better improvement (normalised gain = 0.55) after the active learning instruction, which used a PODS learning cycle designed to challenge and then correct misconceptions (A. P. Mazzolini et al., 2012). The most common student misconception, in this example, centres around a fundamental misinterpretation of the voltage versus time graph. Students with this misconception incorrectly interpret the graph as a snapshot in time (where the solid curve appears to lead the dashed curve).

The above example strongly suggests that students do not learn concepts effectively via transmissive instruction. There are many other qualitative and quantitative examples cited in PER literature (Deslauriers, Schelew, & Wieman, 2011; Elby, 1999; Hrepic, Zollman, & Rebello, 2004; Hussain, Azeem, & Shakoor, 2011; Zavala & Alarcon, 2008). So why then do so many Science, Technology, Engineering & Mathematics (STEM) academics resist changing their traditional ‘transmissive’ teaching practises, especially as STEM disciplines require a sequential learning strategy based on a sound understanding of fundamental concepts?

**Academic Misconceptions: Method of Analysis**

In order to answer the research question posed, namely “Why do academics teaching physics resist moving toward active learning approaches?”, this paper uses a meta-interpretation method (Weed, 2005). This approach draws on previously reported studies by the authors and other researchers, analysing the results of these multiple studies to develop new understandings.

**Academic Misconceptions: The Findings**

The idea of different academic conceptions and misconceptions about teaching and learning is not new. Sandholtz (2011) and Otero and Nathan (2004) both studied the different conceptions of teaching held by
proven. Charles Henderson and colleagues (Henderson, 2004; Henderson & Dancy, 2007; Henderson, Dancy, & Niewiadomska-Bugaj, 2012; Henderson, Yerushalmi, Heller, Heller, & Kuo, 2003; Kuo, Heller, Heller, Henderson, & Yerushalmi, 2002) have shown, for physics in particular, that instructor beliefs are critical in determining teaching practice and implementation of novel teaching methods. In fact in their review article, Henderson, Beach, and Finkelstein (2011) recognised that one of the factors common to effective instructional change was an attempt to work with and change the beliefs of the individuals involved.

At Swinburne University of Technology, within the Faculty of Engineering and Industrial Sciences, members of the ESER group have been trying to develop a culture where academics adopt ‘best practice’ approaches to teaching and learning. ESER members have run many seminars that demonstrate the ineffectiveness of traditional lectures using ESER’s own education research results to support this. Several international education experts have also visited Swinburne to run seminars and workshops outlining successful Active Learning strategies that have been shown to improve students’ conceptual understanding. But still there is a lot of resistance to change in our academics’ teaching practice.

There are many reasons for this academic inertia even within the context of considerable PER evidence showing that traditional transmissive instruction is ineffective. The contributions to academic inertia are many and varied (Gibbs, 1981; Mann et al., 2011) and include:

- **Many academics have succeeded in a traditional education environment- it has served them well:** Because they succeeded in a traditional education system that was centred on the one-way transfer of information (lecturer to student), some academics believe that good information transfer equates to good learning and teaching for most students.

- **Student pass rates are acceptable and students do OK in the final exam:** Some academics often gravitate towards setting predictable exams that, for various reasons, encourage shallow learning and recipe-based problem solving. Some students perform well in these exams yet exhibit poor understanding of key concepts. This may occur because some students find it easier to learn-by-rote (a form of procedural engagement) rather than to develop a deep and connected understanding of the key concepts (cognitive engagement) (Harris, 2008; Streveler et al., 2008)

- **After teaching the same course for many years, academics sometimes forget the difficulties many learners face when first exposed to new concepts (Dubson, 2007):** Preparing lectures for the first time can be a very intellectually demanding and time-consuming activity often requiring several hours or even days of preparation to fully understand the concepts involved. After a few years of teaching though, many academics become very familiar and comfortable with their teaching material and no longer ‘see’ why students should have difficulty in grasping concepts that are explained to them in a succinct and logical manner. ‘Real-time’ understanding of concepts becomes crucial in many STEM disciplines where knowledge and understanding are developed in a structured and sequential manner.

Academic inertia is driven by an academic misconception that can be described as follows:

> ‘If lecture notes are prepared in a logical, thoughtful, coherent and thorough manner and if these notes are delivered via a set of clear and fluent lectures then good learning should occur. If good learning does not occur then the students must be at fault!’

This academic misconception is refuted by the persistent and almost universal poor performance on PER-validated conceptual tests by students in a range of universities and disciplines (Hake, 1998; Hestenes & Wells, 1992; Hestenes, Wells, & Swackhamer, 1992; Lasry, Rosenfield, Dedic, Dahan, & Reshef, 2011; Richardson, 2004; Thijis & Berg, 1995; Zavala & Alarcon, 2008). This very large body of evidence clearly indicates that transmissive passive instruction is far less effective in developing good conceptual understanding than active learning approaches that engage students in the learning process.

Academic inertia is driven by another academic misconception that can be described as follows:
‘If students practice solving typical tutorial and exam problems they will understand the material and pass the exam. This demonstrates that the students are performing well and that traditional teaching works!’

This academic misconception is refuted by the evidence that ‘good’ students who perform well in ‘plug and chug’ style problems and exams often perform poorly on validated conceptual tests on the same topic areas (Mazur, 1997b). In addition, when discussing what their current students have learned from preceding units, some academics are quite critical of the teaching of their peers. At Swinburne, it is not unusual to hear comments like “What did you teach these students last semester- they seem to have understood nothing!” Given that a large percentage of STEM assessment is based around formal problem-solving, it would appear many STEM academics may share this misconception.

**Academic Misconceptions: Discussion and Future Directions**

This paper has argued that a major factor affecting academic resistance to moving toward active learning approaches is that academics themselves have misconceptions about how effective traditional approaches are in helping students learn.

The authors believe that the active learning strategies used to challenge and then correct student misconceptions can also be used to challenge and then correct the academic misconceptions discussed in this paper.

To frame the context of academic misconceptions at Swinburne, the authors have initiated a study to better understand the issues that affect the implementation of research-based lecture strategies amongst Swinburne’s STEM academics. The first phase of this study (which is currently underway) is to survey academics to:-

1. identify the breadth of their experiences around lecturing in both small- and large-class environments,
2. determine academics’ awareness of current ‘best practice’ research-based instructional strategies, and
3. investigate academics’ experiences of implementing these strategies.

The second phase of this study will involve interviewing a small group of academics in order to explore the issues identified from the survey in more depth.

The third and last stage of the study will involve the implementation of an intervention strategy to improve teaching practice amongst Swinburne STEM academics and to test the efficacy of this intervention. The intervention will be part of a program to mentor academics and offer them technical support so that they can easily trial the use of clickers in their lecture classes. This program is designed to promote student engagement in large lectures through the use of clickers. Clickers have been shown to improve learning outcomes in a range of contexts (Sevian & Robinson, 2011) and have been used elsewhere as an avenue for pedagogical reform (Koenig, 2010).

Clickers can give academics instant feedback on how well their students have understood certain concepts and information presented during lectures. At Swinburne, several STEM academics who are ‘early adopters’ of this education technology have given helpful feedback of their experiences using clickers. These academics have found clickers to be very useful both for engaging students and for providing timely feedback on how well their students are learning. For example, one academic has commented “You think you’ve done a great job teaching them then 60% answer ‘don’t know’ to a [clicker] question!”.

The authors of this paper wish to embed a simplified PODS strategy into the mentoring stage of the clicker engagement program. In particular, STEM academics will be assisted to compose some conceptual questions based upon what they’ve recently been lecturing, and to predict how well their students will answer these questions (including the different distracters). The academics will then be supported to trial their questions with clickers in their class. Sometimes what they predict for the percentage of student who will get a conceptual question correct will be higher than what they actually observe. Academics will then
be given the opportunity to discuss with their mentor (who is an academic peer) any differences between their predictions and observations. It is hoped that this sort of focussed discussion about the education research results obtained in their own class may help address any academic misconceptions that may have existed and help them to better synthesise their understanding of learning and teaching.

Other researchers have successfully used peer collaboration to promote teaching practice (Barnard et al., 2011; Henderson, Beach, & Famiano, 2007). These intervention strategies align well with the literature on facilitating research-based educational change. Henderson et al. (2011) identified four features common to the effective change strategies they found in their review, and the authors’ proposed intervention matches these four features (see Table 2).

**Table 2.** Facilitating research-based educational change.

<table>
<thead>
<tr>
<th>Research-based factors common to effective change strategies</th>
<th>Our intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>“are aligned with or seek to change the beliefs of the individual involved”</td>
<td>Will directly target academic beliefs (i.e. misconceptions) about teaching and learning through the PODS cycle</td>
</tr>
<tr>
<td>“involve long-term interventions, lasting at least one semester”</td>
<td>Will support the implementation and analysis of clickers over a one semester course</td>
</tr>
<tr>
<td>“require understanding a college or university as a complex system”</td>
<td>The authors are all at the same institution and have used clickers in their own classes. In this initial stage, they will support fellow academics from the same institution in clickers, with the underlying shared understanding of the local context.</td>
</tr>
<tr>
<td>“designing a strategy that is compatible with this system”</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusion**

This paper has argued that there are several factors that hinder STEM academics from changing their transmissive lecturing practice. This is despite the strong education research evidence suggesting that these teaching practices are ineffective in improving conceptual understanding amongst students. Some of these factors can be grouped together in what the authors have termed ‘academic misconceptions’. This paper suggests that there are parallels in what has been learned about confronting and then correcting student misconceptions and how academic misconceptions might be similarly addressed.

Electronic audience polling devices (or clickers) are currently used in many institutions to improve student engagement in lectures. Clickers also have the ability to give teachers instant feedback on how well their students are grasping specific concepts and ideas. The authors intend to initiate a professional development (PD) program to mentor STEM academics at Swinburne in the use of clickers in their lecture classes and to mentor them in the development of research-grounded multiple-choice clicker questions that accurately determine how well their students are understanding concepts. The PD program will also utilise a modified PODS learning cycle, that will help Swinburne STEM lecturers identify academic misconceptions they may have. Academics will be asked to predict what percentage of their class will correctly answer clicker questions that have been specifically designed to test students’ understanding of concepts that have been recently taught by the lecturer. If the prediction levels are statistically higher than the actual observations, then it is hoped that this may be a catalyst for changing academics’ pre-existing frameworks of their understanding about learning and teaching.
References


WCPE 2012, Istanbul, Turkey


*Proceedings of The World Conference on Physics Education 2012*


Experiential Learning of Classical Mechanics through Molecular Dynamics

Paulo H Acioli* and Sudha Srinivas, Department of Physics and Astronomy, Northeastern Illinois University, Chicago, IL, USA

Abstract

We present a study of the use of molecular dynamics as a tool to teach concepts and practical aspects of classical mechanics to an inhomogeneous cohort of students. The cohort in the study consisted of five students – one senior, two juniors, and two freshmen, neither of who intended to major in Physics. One of the students had two years of physics at high school, three of the students had two semesters of General Physics at the college level (mechanics and electricity and magnetism), and the remaining student had fulfilled all the physics requirements for graduation. The study was conducted over a period of ten weeks as a summer research experience for the students under the advisement of the authors of the present work. Classical molecular dynamics is a computational method used to simulate (integrate) Newton’s second law of motion. In this study the students were asked to use the velocity Verlet algorithm to simulate different systems ranging from analytic and non-analytic textbook examples such as the motion of objects under gravity without and with air-resistance, the dynamics of our solar system, to nominally research topics such as the melting of van der Waals clusters. The Verlet algorithm is based on writing the position, velocity and acceleration of the particles as finite differences. The resulting equations are very simple and resemble the equations of a particle moving under constant acceleration. We encouraged the students to discuss a variety of concepts such as the validity of the equations in the problems they were working on. The most advanced student was very comfortable with describing the problems using potential energy while the ones with limited physics coursework were more comfortable in understanding the acceleration in terms of forces. The discussion was very intense and the most outgoing students would take the lead and write their ideas on the blackboard. It was interesting to see how students’ understanding of the concepts of classical mechanics evolved in the ten-week period. The more advanced students got a deeper understanding of concepts in the act of cognitive rehearsal when trying to make it clear to the novices how the use of energy is somewhat simpler than the forces in describing the dynamics of many particles. At the end of the ten-week period we could verify that the students got a deep understanding of the concepts as measured through presentations made within the group and through the university-wide symposium that marked the culmination of the summer research experience. Other gains that resulted were a firsthand experience with all the steps of the scientific method, learning new computational techniques and a programming language (C++), working on a linux operating system, and learning how to present their knowledge to an audience of different science backgrounds. We plan to continue this study over the next summer when a new cohort of students will be recruited, where we will further validate our findings by using pre- and post-testing of the cohort’s conceptual knowledge of classical mechanics.

Keywords: Experiential Learning, Molecular Dynamics, Classical Mechanics, Cognitive Rehersal

Introduction

Recent Physics Education Research (PER)(Brewe, Kramer, & O’Brien, 2009; Lasry, Mazur, & Watkins, 2008; Fagen, Crouch, & Mazur, 2002; Novak, Patterson, Gavrin, & Christian, 1999; Sokoloff, Laws, Ronald K. Thornton, and et.al., 2004; Laws, 2004; McDermott, et.al., 1996; Sokoloff, & Thornton, 2006; Otero, Pollock, and Finkelstein, 2010; Smith, Wood, Adams, Wieman, Knight, Guild, & Su, 2009) shows that retention of content and conceptual understanding is enhanced by pedagogy that engages the student in the learning experience. Examples of such pedagogies are Peer Instruction, Just-in-Time-Teaching, Real Time Physics, Interactive Lecture Demonstrations, Modeling Teaching to name a few. There is a particular focus on student engagement at Northeastern Illinois University (NEIU), an urban university that primarily serves undergraduates. NEIU’S student population of 13,000 is ethnically.

* Corresponding author. Tel: +1-773-442-4733. Fax: +1-773-442-5710. E-mail address: p-acioli@neiu.edu
and academically diverse with a large percentage of non-traditional and first-generation college students. The vast majority of students are commuters as there is no university sponsored residency. A large percentage of the student population is not well prepared for college level work and one of the ways to overcome this deficiency is through more active learning so that the available learning period is more productive. In addition to the active learning in classes, students have to recognize that their learning gains are also heavily dependent on changing their study habits and being more in charge of their own education. One of the ways to change these habits and have a hands-on experience is through a summer research experience that is not only tailored towards the answer to a research problem through scientific inquiry, but it also aims to teaching fundamental physics concepts and develop strong study habits such as literature reviews, keeping a research notebook, taking data, critical analysis, and scientific reporting.

The research experience described here is targeted at physics majors and minors at NEIU. The upper level courses in the physics department at NEIU are targeted at returning adults and working students. To accommodate this non-traditional student population that makeup the majority of the Physics majors, the upper-level physics courses (as well as the relevant cognates in other STEM departments, that also serve a similar population) are only offered in the evenings. Due to the relatively small number of majors in the department, 25 in 2008, 31 in 2010, and 40 in 2012, and the constraints of work, only a small fraction of the majors/minor are willing or able to work full-time on a summer research project. Therefore, a student research group will likely contain student at different stages of their academic careers, spanning from freshmen to seniors. A successful research/learning experience must be tailored to work with this range of academic background. A research area that can fulfill this requirement is molecular dynamics (MD). Molecular dynamics is conceptually simple and accessible to science college students at all levels. This was highlighted at a plenary presentation at this conference, where the Molecular Workbench (Tinker, 2012; Xie, R. Tinker, B. Tinker, Pallant, Damelin, & Berenfeld, 2011) was shown to be of great utility in teaching physics to students at different levels. Some of the applications were as simple as a gas of interacting particles and the discussion of energy exchange in confined systems. Advanced applications included the interaction of light with matter interaction and fluorescence. In the plenary presentation, the emphasis was on the use of simulation to understand concepts at the molecular level without necessarily having a complete understanding of the computational method behind it. In this work however, since the researchers are Physics majors and minors who have enough of a background of Classical Mechanics, we also have the expectation that the students make gains in their understanding of classical mechanics through simulation. Further, we want the students to assimilate these concepts through a deep understanding of the method and its applications to different systems. The systems studied range from textbook problems such as the motion of particles with and without air resistance, motion of celestial objects such as planets, asteroids, comets, stars, to research projects such as the melting of atomic clusters and the dynamics of biologically relevant systems. The common thread that linked these projects, and allowed smaller groups of students to work collaboratively, was the use of Molecular Dynamics (MD) techniques in each of these projects. MD is a computational method that is efficient, uses modest resources, can be tailored to the length of time available, and it is suited to students with different academic backgrounds or levels; it is strongly linked with classical mechanics which is a basic first course in the physics curriculum and is a common denominator from freshman to juniors; it can be applied to hard to solve textbook problems to cutting edge research in the areas of material science, astrophysics, and biophysics just to name a few (Aarseth, 2003; Baaziz, Bégin-Colin, Pichon, Florea, Ersen, Zafeiratos, Barbosa, Bégin, & Phan-Huu, 2012).

In this paper, we report the results and the pedagogical outcomes of a summer research project undertaken under our supervision by 5 physics students — 2 freshmen, 1 sophomore, 1 junior and 1 senior. The students all had to learn the basics of classical mechanics, to program in C++, and to conduct a research inquiry where they had to navigate through all the stages of the scientific method. We observed the student interactions in the cohort as well as their progress through their academic careers. The research experience and the results were very positive. In the next section we describe Molecular Dynamics and how it is used to teach Classical Mechanics. We also describe the research environment and how student pedagogical gains were observed and analyzed. In the following section we present some of the results from the student research and how these impacted student participant’s learning of physics concepts and methodology. The final section is dedicated to the conclusions from this work as well as to the plans of future research in the subject of experiential learning through research experiences.
**Methods**

In this section we describe molecular dynamics and explain why this computational method is a great tool in solving problems in classical mechanics where an analytical solution may not exist (or be hard to obtain, as the case may be) as well as how it helps students understand concepts of classical mechanics, thermodynamics, and molecular interactions.

The basis of MD is the set of Newtonian equations of motion for an \( N \)-particle system

\[
m_i \ddot{r}_i = \vec{F}_i(r_1, r_2, ..., r_N) = \nabla_i U(r_1, r_2, ..., r_N) \quad i = 1,2,...,N.
\]

If one knows the forces acting on the particles \( \vec{F}_i(r_1, r_2, ..., r_N) \) (or alternatively the total potential energy of the system \( U(r_1, r_2, ..., r_N) \)) and the initial conditions one can, in principle, determine the positions and velocities of all the particles at all times. An analytical solution of Eq. (1) is not always possible and numerical solutions are needed. These computer simulations were first carried out by Alder and Wainwright (Alder, & Wainwright, 1957; 1959) for a system of hard spheres. These methods were then generalized to physical systems, such as liquid Argon using the Lennard-Jones (L-J) potential, by A. Rahman (1964). Further enhancements in the algorithm made by Verlet and are still widely used today, and the methods we chose to use in this work is the Verlet algorithm (Verlet, 1967). This method simplifies the process of solving the differential equation in (1) by approximating the differential equation with finite differences. In this method if one knows the position \( r_i \) and velocity \( v_i \) of the particle \( i \) at time \( t \) one can obtain its position and velocity at time \( t + \Delta t \) as

\[
r_i(t + \Delta t) = r_i(t) + v_i(t) \Delta t + \frac{1}{2} a_i(t) \Delta t^2
\]

\[
v_i(t + \Delta t) = v_i(t) + \frac{1}{2} (a_i(t) + a_i(t + \Delta t)) \Delta t
\]

where

\[
a_i(t) = \frac{\vec{F}_i(r_1, r_2, ..., r_N, t)}{m} = -\frac{\nabla U(r_1, r_2, ..., r_N, t)}{m}
\]

is the acceleration of the particle and can be determined if we know the interaction potential (as given in an analytical form like the L-J potential, for example) or are given the forces acting on the particle at time \( t \). This approximation works very satisfactorily for small time steps, \( \Delta t \). Another advantage of these equations is that these demonstrate that any physical system can be considered as having a constant acceleration, as long as the time step chosen is small enough. This allows students who have only had the introductory physics sequence to solve problems that use very realistic interactions and to be able to understand the trajectory of the particle without analytically solving the equations of motion. Current MD codes are based on the same ideas but typically use higher accuracy finite difference approximations or integration techniques (Frenkel, 2002). They are applied in problems such as melting of clusters (Ghatee, & Shekoohi, 2012) and biologically relevant problems such as transport properties across membranes (Gamini, Sotomayor, Chipot, & Schulten, 2011). Our focus in this work is to determine the benefits of a research experience using MD in learning classical mechanics. Namely, students can understand very complex motions by breaking it down into constant acceleration portions. Students are able to easily and accurately study problems that involve air resistance. MD can be easily applied to describing the motions of a few to many interacting objects, such as a gas of interacting molecules or several celestial objects. Students will have an appreciation of the importance of the potential energy in understanding the dynamics of a system. We now turn our attention to the research experience and how it affected the students’ learning of classical mechanics and their progress towards their major.
We observed our cohort of two freshman, one sophomore, one junior, and one senior, five students in total. One of the freshmen was a mathematics major pursuing a physics minor and the remaining four students were all physics majors. The students all had different physics backgrounds – one of the students had two years of physics at high school, three of the students had two semesters of general physics at the college level (Mechanics, i.e. Introductory Physics I and Electricity and Magnetism, i.e. Introductory Physics II), and the senior student had fulfilled all the physics requirements for graduation. The experience spanned 10 weeks and the minimum requirement was 20 hours per week, on campus and working together in the computational laboratory. The students worked together in different aspects of the project and met twice weekly with the faculty to assess their progress. The observations are described in the next section.

Observations
The students were posed with the problem of understanding the dynamics of melting of small van der Waals clusters. The initial discussion was focused on what tools and scientific knowledge were needed to solve the problem. Once it was established that computational simulation was the only practical route to answering the questions posed, students were introduced to molecular dynamics as one of the conceptually simpler and robust methods. The first task was to come up with problems that could be solved analytically to use as benchmarks to test the computational code they were going to develop. Then they were tasked with learning MD, C++, and to program a simple and robust MD code that could be applied to the test problems and later extended, through the use of an appropriate analytical two-body (or many body) potential, to treat the original research question. The chosen test problems were: a free falling object under constant gravitational force without air resistance; a free falling object under $1/r^2$ gravitational force; objects falling under the action of gravity with and without air resistance; projectile motion without and with air resistance (linear and quadratic); the orbit of the Moon around the Earth; and the orbital motion of the planets around the Sun. At this stage they had to review concepts of free fall, conservative and non-conservative forces, potential energy, motion under the action of a central potential, conservation of angular momentum, and Kepler’s laws. Some of the test problems had analytical solutions while others only had qualitative descriptions. This mix of problems allowed the students to have a deeper understanding of concepts they had already learned in their course work. It also allowed students to make an educated guess about situations they could only treat numerically and were able to analyze whether or not the results of their simulations were realistic.

There were several layers to the dynamics of the cohort. Some of the students, such as the Math major, were more mathematically inclined, others had a stronger programming background, and some had more physical intuition. Although all the students had to participate in all the stages of the project, these differences led the students to focus on their strengths. The senior in the group had participated in a research experience on molecular modeling in the previous summer and was the liaison between the faculty and the other students. He and another student had more programming experience and were placed in charge of teaching the other students the basics of Linux and programming in C++. Students with stronger mathematics background worked on the analytical solutions to the test problems and discussed these solutions with the rest of the group.

Students with more physical insight helped analyze whether the results of the simulations where realistic or not, and provided important feedback that was essential for troubleshooting the several stages of the program. The computational laboratory had a round table, 3 computer stations, two walls of blackboards and a mini library. This setting was essential for group work and collaboration. The students were always at the board having discussions on every aspect of the project, be it reviewing concepts, working on an analytical solution, or learning to program. In fact, one blackboard was dedicated to programming issues, and the other to analytical issues. It was interesting to see the evolution from students initially focusing on their strengths to a broader participation in the whole project. As the experience progressed each student become more comfortable in explaining a particular aspect of the project.

The first test problem was simulating a free falling object under the action of a constant gravitational acceleration. All the students were very familiar with the equations of motion with constant acceleration and it was the ideal problem to test the code. They assumed $g = 9.8 \text{ m/s}^2$, set an initial height $y_0$ 1.5
m above the ground and assumed an initial velocity of 5 m/s in the +y direction. When the students ran the simulation they noticed that the object never stopped and continue to drop well beyond the ground as indicated by the graph in Fig. 1. This result stimulated an animated discussion about modeling in general. The students started with the fact that they did not account for the ground in their simulation. The discussion went beyond as they had the same questions with the analytical equation of motion \( y = y_0 + v_{0y} t - \frac{1}{2} gt^2 \). While trying to find the time when the object hits the ground they found the two solutions -0.24s and 1.26s. They discussed the meaning of the negative solution and realized that every model can only be applied within certain limits and parameters. More importantly they learned that although the mathematical domain of the equation is \((-\infty, +\infty)\), the physical domain is [0, 1.19s]. This is a very important step in scientific inquiry. Modeling is frequently invoked when trying to explain a scientific observation and the realization of the limitations of a model is often overlooked by young, undergraduate students. Finally, they discussed whether or not the assumption of constant acceleration (or force) was reasonable.

The natural step was then to test the code using Newtonian’s law of gravity. The only change in the program was to replace the potential energy (in effect, the gravitational potential) with the more appropriate expression. Students analyzed the analytical and numerical results and realized that, for small heights as compared with the radius of the Earth, the results did not deviate significantly from the constant acceleration hypothesis. Nevertheless, they saw the advantages of using the more general expression as the program could be used not only to study free fall and projectile motion, but it could also be used to study satellite and planetary motion. Before we turn to the celestial objects, however, let us address our observations of the student discussions on the simulations of projectile motion with and without air resistance. The tests without air resistance confirmed the textbook results and this time the students made sure the simulation stopped once the projectile reached the ground. They discussed, however, how to include the topography as well as how to realistically include the interaction of the projectile with the ground. The tests with air resistance, on the other hand, were very interesting. The group started with a drag force that may have both a linear or quadratic dependence on the velocity of the object, or

\[
\vec{F}_{air} = -(c_1 + c_2 v_0) \vec{v}.
\]  

The students decided to simulate a cannon with muzzle velocity of 321 m/s shooting a spherical ball at a 45° angle. They ran the simulation with no air resistance \((c_1 = c_2 = 0)\); with linear air resistance \((c_1 = 0.4, c_2 = 0)\); and with quadratic air resistance \((c_1 = 0, c_2 = 0.4)\). In Fig. 2 are the results under these conditions. One can see that the maximum reach with linear air resistance is substantially less than the value with no air resistance. The reach of the projectile under quadratic air resistance is so small that one cannot see it in the graph. One of the students quickly concluded that the quadratic air resistance would stop the object much quickly than the linear case. However, one of the students with more physical insight did not think the simulation was very realistic. Initially the discussion was focused on whether Eq. (5) correctly modeled air resistance but it later moved to the chosen values of the coefficients \(c_1\) and \(c_2\), that they identified as the drag coefficients of a rough sphere. What they overlooked was the fact that the expression of the force in terms of the drag coefficient is given by

\[
\vec{F}_{air} = -\frac{1}{2} \rho A c_d \vec{v} \vec{v},
\]  

instead of Eq. (5). The coefficients \(c_1\) and \(c_2\) contain the air density and the area of the object and are therefore much smaller than 0.4. They learned the importance of considering appropriate values for the external parameters in the model, more importantly they learned that it is fundamental to any computational project to analyze if the results of the simulation conform to their observation of reality. In Fig. 3 we present the results with realistic values for the coefficients \(c_1\) and \(c_2\) in Eq. (5). With more realistic values of the coefficients, the linear resistance becomes very small and there is no noticeable difference from the case with no air resistance and a more realistic outcome results with the quadratic air resistance.
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The next set of test problems was to simulate the motion of celestial bodies, such as the motion of the Moon around the Earth and the motion of the Earth around the Sun. These simulations outlined the importance of initial conditions and time scale in physics. For example, the students simulated, with success, the motion of the Moon around the Earth separately and the motion of the Earth around the sun separately. When they tried to simulate the combined Sun-Earth-Moon system they used the same initial conditions from the previous simulations. They transformed the position of the Moon from the Earth’s reference frame to the Sun’s reference frame. However, they did not transform the initial velocity of the Moon to the Sun’s frame. The trajectory of this simulation is shown in Fig. 4. One can see that the Earth follows its normal trajectory. However, the Moon was found to move in an elliptical orbit around the Sun instead of orbiting around the Earth. Although this simulation is physically plausible it did not correctly describe the desired situation. This shows, in a very effective way, the importance of initial conditions in physics. An accurate description of a physical phenomenon depends on correctly representing the interactions, using the proper computational tools, as well as starting with the appropriate set of initial conditions.

Once the students were convinced that the program worked properly in all the problems tested in, they moved to the research question of melting of clusters. The students had to deal with the following issues: how the temperature of a single molecule is defined; how different the molecular time scale is (in contrast to the time scales they had used in their prior treatment of problems in classical mechanics); they were introduced to a realistic potential energy that represents weakly bonded systems such as the rare gas atoms; they had to understand what exactly serves as the signature of melting in finite systems. The temperature of a single molecule was defined as the kinetic energy of all the atoms divided by the number of degrees of freedom. Students were asked to find the frequency of oscillation of the clusters through the simulation. When doing so they realized that the time scale at the atomic level was completely different than those of the previous simulations. They were using atomic units for all the quantities and assumed that the time was given in seconds. There was a huge discrepancy between the calculated results though the harmonic approximation and the results obtained in the simulation. After lengthy discussions the students realized that the time step in the atomic units used for these simulations amounted to 2.42 x10^-27 s. One of their discussions was that Eqs. (2) and (3) are valid for small time steps, and that a small time steps is different depending on the observed phenomena. The time scale for planetary motion is measured in years, for projectile motion in seconds, and for phenomena at the atomic scale the typical time scale is of the order of 10^-12 s. Another important part of this research project was to use realistic interactions. For noble gases a good starting point is the Lennard-Jones pair potential that correctly models weakly bonded systems. The students were able to derive the attractive portion of the LJ potential by modeling the interaction between pairs of noble gas atoms using the model of two fluctuating dipoles and then adding the Pauli repulsion term and analytically finding the equilibrium distance for the diatomic molecule and analyzed the motion of a diatomic molecule in terms of the potential and its turning points. The students then compared their analysis with the simulation of the same diatomic molecule and were satisfied that the program was correctly simulating it. This gave them confidence in their results for the larger size clusters. Before they could move forward they needed to address melting of a single molecule. Their first definition of melting came directly through the visualization of the simulations of the clusters at different temperatures. They observed that above a certain temperature the atoms within the molecule were able to exchange position and change shape of the molecule, a phenomenon they identified as melting. Although this observation is useful, it was hard to pinpoint a phase transition in a similar fashion to what is done in bulk matter. A literature review showed that one can also understand the melting by calculating different quantities such as the pair distribution function, which is the probability to find a particle at a certain distance from another one. An alternative quantity is the relative root mean square deviation (rms) of the bond lengths, given by

\[
\left\langle \delta r_i \right\rangle_{\text{rms}} = \frac{1}{n} \sum_{i < j} \sqrt{\left\langle \delta r_i^2 \right\rangle - \left\langle r_i \right\rangle^2}
\]
This quantity indicates how the bond length of each pair of atoms deviates from its average. A sudden change in this quantity indicates that the atoms in the molecule are no longer just oscillating about their equilibrium positions. The atoms can exchange positions and the molecule can change shape, but they are still somewhat bound to one another. In Fig. 5 we show a graph of the relative rms of the bond lengths for Ne4. One can see that there is a sharp increase in the relative rms at a temperature of approximately 32.5 K, indicating the onset of melting. This was also confirmed by the visualization of the simulations at the different temperatures. This problem shows how a student can understand the basics of classical mechanics, thermodynamics, and statistics by tackling a research question. One can bring these questions into the classroom to help students to make the connections between concepts and techniques that are learned in different classes thus making the class more appealing, quantitatively relevant to students, and thus helping in the retention of the content.

Concluding Remarks

Small group makes quantitative assessment challenging, however a qualitative assessment showed clear gains. For instance, the collaboration between students of varying ages, academic levels, majors, academic preparation, and diversity naturally led to peer interactions, and peer-mentor interactions. The requirement of on-site presence, something that is challenging on a commuter campus in general and for the group, in particular, as it included traditional and non-traditional students who had full-time employment. The difficulty in scheduling had the effect of creating closer ties among students since communication (in person and through electronic means) was essential. The requirement of individual presentation to a university-wide audience also was of great impact. The preparation of posters/presentations and training included multiple iterations and both peer and faculty input were utilized. These resulted in better written and oral communication skills. In terms of knowledge we can point to the following gains. An overall strengthening of the student’s backgrounds in classical mechanics - led to 4 better prepared students in classical mechanics over the next semesters. There was also gain in knowledge on issues that might not be part of the standard curriculum. Students taking introductory and intermediate classical mechanics courses become adept to varying degrees, at solving problems or rather exercises, that are clearly laid out, for which realistic parameters are generally provided and for which realistic solutions exist. In applying molecular dynamics techniques to solving even the so called “text book” type problems in classical mechanics, the students had to think critically about what those realistic parameters might be, what the initial conditions should be and even as they proceeded with the methodology itself. Often, they had to go back to correct for injudiciously chosen initial conditions or realized that their questions had not been appropriately formulated. Learning to pose questions and seek the answers to these questions leads to higher retention of concepts. The students also acquired computational skills such as learning a computational language such as C++, exposure to linux operational system and commands, and training in using molecular visualization tools. All of these factors lead to a cohort of students with a well rounded education in classical mechanics.

Our intention for future work is to conduct a similar type of research experience using the same or other computational simulations, and determine learning gains through pre- and post-tests and to expand the study to experiential learning through experimental research experiences.

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References


Figure 1. The graph of the height of an object thrown up in the air and under the action of a constant acceleration due to gravity. The solid black line represents the expected result and the dashed red line is the result of the simulation.

Figure 2. The graph of the trajectory of a projectile with no (black line), unrealistic linear (red dashed line), and quadratic (green line) air resistance.
Figure 3. The graph of the trajectory of a projectile with no (black line), realistic linear (red line), and quadratic (green line) air resistance.

Figure 4. The trajectories of the Earth (full line) and the Moon (dashed line) in the reference frame of the Sun for a poor set of initial conditions.
Figure 5. The relative root mean square deviation of the bond lengths in Ne$_4$. 
Teaching Physics with Soccer

Fabrizio Logiurato, Mauro Rossi and Luigi Gratton, Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo, Trento, Italy

Abstract

Soccer is considered one of the most loved sport in the world. With the aim to exploit such a popularity among High School students, we propose to analyze many physical aspects of this game. Connections with other sports are established as well. The study of physical phenomena in soccer is performed through simple experiments, digital analysis of images and videos with free software, and by watching famous soccer players’ performances.

Introduction

We have developed a didactic project which proposes to illustrate many principles of the elementary physics with examples taken from the soccer sport. In this way, being this game very beloved among young people, we hope to pour some of students’ interest also toward the physics. Moreover, soccer allows us to accompany with examples of the real world physical subjects often considered distant from the everyday life and rather boring. Our project is at the present time in preparation and it is part of a course for High School teachers.

Within such a proposal, we study the kinematics and dynamics of a ball and other flight objects by considering the effects of air friction and fluid dynamics. In the absence of wind we expect the trajectory of the ball to be in a vertical plane in the direction of the kick. Actually, a lateral force acts on a spinning ball in the air and this can curve the trajectory. Such a phenomenon, known as Magnus effect, is observable in many ball sports, like baseball, tennis, table tennis and cricket, not only in soccer. This gives us the opportunity to present some simple experiments in order to introduce such effect, together with some fundamental concepts of fluid dynamics. We also study the mechanics of the kick, the impulsive forces and the elastic and inelastic collisions between feet, heads and balls. We also make experiments on the mechanics of the bounce of a ball, and on the conservation and dissipation of energy related to it. The bounce can be a good original example of application of the Hooke law. To this aim, a simple model of the ideal bounce is developed and experimentally verified. Also some notion of biomechanics is introduced studying the physics of walking and running.

In this paper we shall present some examples considered in our project such as experiments about the Magnus effect, the physics of the bounce and the study of the leg as a physical pendulum in order to analyze the physics of walking.

The Magnus effect

The Magnus effect is the phenomenon that we observe on a spinning object when it moves with respect to a fluid with viscosity (Wesson 2002, Mehta 1985). The effect was discovered by the English physicist Peter Tait in ’800 while he was analyzing the motion of golf balls. But its physical explanation is by the German Heinrich Gustav Magnus and its studies of ballistic. Nevertheless, also Newton, in a communication to the Royal Society of 1671 described the phenomenon, noticed while he was observing some students of Cambridge playing tennis (Newton, 1671-1672).

The effect is caused by the air viscosity and by the existence of the boundary layer, a narrow layer near the surface of the ball in which the effect of viscosity is important. Because of air viscosity, the spinning ball drags and bends the air from its initial direction and for the principle of action and reaction the ball is subject to a sideways force (Fig. 1).
Figure 1. In the Magnus effect a ball in relative motion with respect to a fluid is subject to a sideways force. In quantitative terms, the intensity of such a force for a sphere is:

\[ F_L = C_L \rho D^3 f v, \]

where \( C_L \), \( \rho \), \( D \), \( f \), and \( v \) are the density of the air, the diameter of the sphere, the frequency of rotation, the speed of the ball, and a coefficient which for the air is equal to 1.23 (\( L \) is for lift). The Magnus effect is at the base of the explanation of the banana kick, the famous effect where the ball performs a sideways curve and for which the Brazilian player Roberto Carlos is famous. We can watch a beautiful example of banana kick in the YouTube video: http://www.youtube.com/watch?v=W5XpXU8TB0o

Simple experiments about the existence of the viscosity and boundary layer can be done with honey, air or water. For example, with honey and with small strips made of toothpaste and an object which is in moving in the honey, we can explain the drag effect of the fluid near the object and show the boundary layer. Such an experiment is visualized in Fig. 2.

Figure 2. The honey near an object in moving is dragged to follow the motion of the object because of the viscosity.

We also have developed small devices that allows us to launch spinning objects, like light cups of expanded polystyrene and little balls. The devices are made with rubber bands, sticks and clothes pegs (Fig. 3). The students can build their own throwers in order to experiment the properties of the Magnus effect, for example, as it depends by the frequency of the rotation and by the direction of motion of the object. Tracker software allow us also some quantitative considerations, how one can see in the papers of Cross (2012) and Ireson (2001).
Consider a ideal bounce of a soccer ball, that is a completely elastic bounce, without loss of energy of the ball. It is possible to show that in such a case, during the time of bounce, the ball is subject to an elastic force which follows the Hooke law and the deformation of the ball against the floor follows a harmonic law (Wesson, 2002). In fact, consider

\[ r = \text{radius of the ball} \]
\[ F = \text{resulting force} \]
\[ p = \text{air pressure in the ball} \]
\[ A = \text{area of contact} \]
\[ s = \text{deformation depth} \]
\[ m = \text{mass of the ball} \]
For sake of simplicity, we consider just the one-dimensional case with the reference axis as in Fig. 4. During the bounce the force on the ball along $x$ axis is given by:

$$F = -pA,$$

where, if the deformation $s$ of the ball is small and we can neglect terms with $s^2$, approximately, from the Pythagoras theorem, we have for the area of contact:

$$A = \pi \left[ r^2 - (r - s)^2 \right] = 2\pi rs.$$

If $v$ is the vertical velocity of the center of the ball:

$$v = \frac{ds}{dt}.$$

With the previous equations it is not difficult to show that:

$$\frac{d^2s}{dt^2} = -ks, \quad k = \frac{2\pi rp}{m}.$$

The solution of this equation is the harmonic motion:

$$s(t) = \frac{v_0}{\sqrt{k}} \sin(\sqrt{kt}),$$

where $t=0$ is the time of the initial contact and $v_0$ is the magnitude of the vertical velocity at that time. We can calculate the bounce time, that is, when $s$ is zero again:

$$\sqrt{kt_0} = \pi, \quad \text{with} \quad t_0 = \frac{\pi m}{2rp}.$$

Our laboratory soccer ball has the following properties:

$$r = 0.109 \text{ m}$$

$$\rho = 0.318 \times 10^5 \text{ N/m}^2$$

$$m = 0.38 \text{ kg}$$

With these parameters our time of bounce is valued to be about $t_0 = 13$ milliseconds.

With the purpose to verify experimentally this model, we have made a high speed movie of the bounce of our soccer ball (see Fig. 5). We have used a Casio Camera, High Speed Exilim EX-FH20 with 1000 frame/s. For data analysis we have used Tracker software. Tracker is a free video analysis and modeling tool built on the Open Source Physics (OSP). It can be downloaded at the address: http://www.cabrillo.edu/~dbrown/tracker/
Figure 5. Frame of a high speed movie of a bounce analyzed with Tracker Software.

In Fig. 6 we have valued the bounce time considering the time that the ball employs to reverse its speed. The measured value is about 10 milliseconds, in accord with the theoretical value.

![Bounce Time Graph]

Figure 6. Measurement of the time of a bounce.

We have also compared the theoretical deformation $s$ and its harmonic motion with the experimental curve obtained by Tracker software. The experimental curve with its errors has been valued after a series of five tests. In Fig. 7 we can observe that the accord between theory and experiment is quite good.
Figure 7. Comparison between theoretical model (red) and experimental curve (blue) of the deformation $s$ with respect to the time $t$.

**The Leg as a Physical Pendulum**

As last example, we propose to study the fundamental mechanical principles of walking and running approximating the leg by a rod with uniform cross section (Davidovits 1975; Bartlett 2002; Jones & Childers 1993). The period of a freely swinging rod supported at its upper is

$$T = 2\pi \sqrt{\frac{2L}{3g}},$$

where:
- $T$ = period of the pendulum
- $L$ = length of the pendulum
- $g$ = acceleration of gravity

$v_{\text{walk}}$ The factor $2/3$ derives from the mass distributed uniformly along the rod. The walking speed depends on the leg length. If we consider the walking speed proportional to the gait, and this proportional to the leg length:

$$v_{\text{walk}} \propto \frac{L}{T/2} \propto \sqrt[3]{L}.$$

So, if we assume minimum energy expenditure, people with longer legs have a more rapid natural walking gait. The leg length of the person in Fig. 8, measured from the hip, is about:

$L = 0.80\, m$.

Our approximated theory gives us for the period of the leg with the previous length:

$T_r = 1.5\, s$.

The experimental measurement of $T$ valued with Tracker software (see Fig 8) gives us, for a freely swinging leg, (as relaxed as possible):

$T_s = 1.4\, s$, in good accord with the theory.
$T \propto L$. If a person runs we have a force applied by the muscles and a torque on the pendulum, so this is no more free. One can show in this case, see, for instance, Jones & Childers (1993), that and, because the speed of running is again

$$v_{\text{run}} \propto \frac{L}{T/2},$$

now the speed does not depend on the length of the leg: this is a luck for soccer players like Maradona who are not very tall, and also for small animals (in reality, it is necessary to consider also other factors as, for instance, the fact that people with legs of equal length can have different muscular mass).

**Conclusions**

Sport can be a great source of interesting applications of elementary physics in the real world. Although from the point of view of the advanced research the sport physics is enough developed, from the didactic point of view its potentiality has not broadly been still exploited. In this work we have given some examples of application of elementary mechanics to the physics of soccer. Now free software and cheap high speed camera allow to perform new experiments in which physics teachers can work together with physical education teachers and their students in the soccer field or in the gym.
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PBL in Mechanics: some results of a controlled experiment

Géraldine Poutot*, Adriana Bacila, Philippe Ageorges and Bernard Blandin – CESI-LIEA

Abstract

This paper presents the first results of a controlled experiment of the application of the Problem-Based Learning approach in the first-year course of Mechanics in our School of Engineering. The PBL approach was implemented in parallel with traditional course and exercises. Students take pre-tests and post-test to measure the progress in conceptualization, and the same exams at the end of the course to measure the achievements of the learning objectives. The results of the two learning paths are compared and discussed.

Introduction

In many countries, learning sciences and technology is becoming less and less attractive for young people. At the opposite, firms need more and more competent persons in scientific and technical domains. To try and resolve this paradox, Cesi School of Engineering decided to test in 2011 the implementation of Problem-Based Learning (PBL) in the field of Mechanics. This approach was not chosen at random: Cesi School of Informatics had already been using it for its entire 5-year curriculum since its creation in 2004 (Maufette & Allard, 2005), and its efficiency to develop professional competency and achieve learning outcomes, together with raising interest in the subject learned has been demonstrated, at least in Medicine (Albanese & Mitchell, 1993; Vernon & Blake, 1993) and in Informatics (Drohan, Maufette, Allard, 2011). The reasons to use this approach in Physics have been explained in a detailed way in our paper presented by Bernard Blandin at the GIREP-ICPE-MPTL 2010 Conference (Blandin, 2010).

Before describing the experimentation and its results, a short presentation of the PBL approach, which was requested by the participants during the workshop in Istanbul, will facilitate the understanding of the rest of this article.

Problem-Based Learning was pioneered in the late 1960’s, in a Medical School programme in Canada, at McMaster University (Hamilton, Ontario). Howard Barrows and his colleagues noticed that even if their students had learned many disciplines during their curriculum, they were unable to use their knowledge for clinical applications, such as diagnosing a given disease, when confronted with patients. It appeared that diagnosis required a specific way of reasoning which was not (and cannot be) acquired simply by attending courses in several disciplines. This way of reasoning and mobilizing knowledge from different disciplines results from the experience and can only be acquired by being confronted with multiple and varied cases. So, PBL was first invented as a way to simulate clinical situations in which the students were confronted with multiple and varied study cases reporting real patient diseases.

After the publication of their seminal book (Barrows & Tamblyn, 1980), PBL approach developed widely throughout medical education (including dentists, nurses, paramedics…) during the 1980’s, and then spread out to other domains, such as teachers training, business, engineering, science or architecture (Savery, 2006; Walker & Leary, 2009). PBL has already been used in Physics (Raine & Symons, 2005; Ali & Rubani, 2009; Sahin & Yorek, 2009), at different levels (from High School to Master courses), with contrasted reported results.

Cesi School of Engineering uses quite the same structure for a PBL session as the one used in Cesi School of informatics. This structure can be considered as the standard approach (Bonvin & Lanarès, 2002). The structure of a session comprises three main phases, with the following activities (“Prosit” stands for Problem Situation).

* Contact author e-mail: gpoutot@cesi.fr
**Phase 1: “Prosit Go” [PG] (work in small groups of about 12 students)**

1. Organizing the session and attributing roles
2. Defining and clarifying the problem / situation
   3. Analyzing learning needs
   4. Generalizing ideas
   5. Finding solutions tracks
3. Elaborating an action plan for learning

**Phase 2: Studies and Research Activities [SRA] (individual work)**

1. Carrying out the action plan for learning

**Phase 3: “Prosit Return” [PR] (same small group as in Phase 1)**

1. Presenting solutions / results and the work done during Phase 2
2. Presenting detailed calculations (if requested)
3. Debriefing group work and individual work

The sequencing of a PBL Session is the following: a first phase, called “Prosit Go” (PG) allows distributing roles to the group of students (Chair, Secretary, Time Keeper...), to organize the work for the whole session and to precisely define the issues which are to be addressed in the session: What is the question? What type of solution is expected? What do we need to know to be able to propose a solution? Etc. A second phase, named “Studies and Research Activity” (SRA), allows the students to use given resources to learn individually what they need to learn and to propose a solution to the problem. This phase can be punctuated by “Workshops” (i.e. time devoted to the resolution of exercises), or by conferences of a domain expert, providing further information about the issues. Finally, a debriefing phase, called “Prosit Return” (PR), allows to synthetize the elements of answer provided by the students and to demonstrate that the required learning outcomes are acquired. The PG and PR phases are supervised by a tutor, the role of which is to help the students by means of questions when they feel blocked. SRA is a self-study period.

The following diagram (Figure 1) presents the organization of the different sequences during the week. The rest of the time is dedicated to other activities, related or not to the problem.

The program in Mechanics in the first year is covered by six problems, designed by three teachers / researchers in order to lead to the same learning outcomes as the traditional course and exercises in Mechanics. Details and examples are given in our previous paper (Blandin, 2010). The first two problems form a module called “Harmonization in Mechanics”. It is a revision module, which deals with Statics. The four others form the First-year Course in mechanics itself, and deal with Kinematics and Dynamics. The teachers also designed written tests, one for each module, to assess the learning outcomes.

**Methodology**

Three centres participated in this experimentation: Nanterre with 120 students, Saint-Nazaire with 39 students and Pau with 60 students. The experimentation aimed at comparing the results of two different pedagogic approaches: Problem-Based Learning and traditional course and exercises.

Students were divided into two groups of identical size. One of the groups did traditional teaching while the other group participated in the Problem-Based Learning sessions. To compare both approaches, the following protocol was set-up: the students take the same exams to measure their knowledge acquisition, one after each module, and take two tests in order to evaluate progress in mastering the concepts and principles of Newton’s physics. The tests we used were built by a team of the Arizona State University several years ago, and are now validated worldwide in several languages. These tests are the Force Concept Inventory (FCI) and the Mechanic Baseline Test (MBT) developed by David Hestenes and his colleagues (Hestenes & al., 1992; Hestenes & Well, 1992). The FCI was taken by all the students before and after the Harmonization Module, the MBT was taken by all the students before and after the Course itself.

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Our main hypothesis was based on several meta-analysis results reported by Savery (2006) and those more recently obtained by Walker & Leary (2009): both approaches lead to the same acquisition of knowledge (comparison of the exams results); Problem-Based Learning allows improving conceptualization and physical reasoning (comparison of FCI and MBT results taken as pre-test and post-tests).

The results which will be presented in the next section are quantitative as well as qualitative. The quantitative results are provided by the marks at the exams, and by the gains between the first and the second take of the two assessment tests, FCI and MBT. The qualitative results comes from observations and discussions with the students, collected for their Master thesis by two students of an Educational Sciences programme from Paris Ouest – Nanterre University, Beatrice Vicherat (Vicherat, 2011) and Mathieu Gandon (Gandon, 2011).

**Data and Findings**

**Quantitative results: the exams**

Acquired competencies are validated by the exams. The evaluation of the learning outcomes uses a Rubrics grid (Taggart & al., 1998) which measures the achievement of each learning objective, the methods of reasoning as well as the behavior of the student during the PBL sessions. This grid is based on Bloom’s taxonomy (Bloom & Krathwol, 1956). To be able to study the distribution of notes and make statistical analyses, notes A, B, C and D were replaced by their minimal values, i.e. A=3.6, B=2.6, C=1.6 and D=0. According to this modality of evaluation the maximum note is 4. Marks got at the exam after the Harmonization module are synthetized below (Figure 2) for every center. PBL group is noted PBL, and traditional teaching group TT.
Results of the exam after Harmonization are higher in PBL’s groups than the other groups for the centers of Saint-Nazaire and Pau. However the discrepancy is not statistically significant using variance analysis ($p >> 0.05$). It is the opposite in Nanterre, where the discrepancies are significant ($p = 1.42637 \times 10^{-5}$). Results got at the second exam after the course in Mechanics are synthetized below (Figure 3), in the same way as before.

Concerning the exam after the course in Mechanics, which dealt with kinematics and dynamics, the results are similar. PBL brings better results for the centers of Saint-Nazaire and Pau, the discrepancies not being significant, and conversely for Nanterre.

These results will be discussed in the final conclusion, taking into account qualitative data.
**Quantitative results: the FCI**

The FCI measures the understanding of concepts (speed, acceleration, force) and the mastering of the Newton’s mechanics basic principles and their application in simple situations. The «Newtonian threshold» is considered as reached when the score exceeds 60% of good answers to the 30 questions of the test, i.e. when the mark is superior to 17 out of 30 with 1 point for each question. The students take this test before beginning the Harmonization module, and again after the end of the Harmonization module. The gain between the two takes measures the impact of the pedagogical method. The center of Nanterre had started the Harmonization programme taught in the traditional way before the installation of the test on the Moodle platform. So, the results of Nanterre for the traditional teaching group are missing. Problem-Based Learning group is noted PBL and the traditional teaching group is noted TT. Results are provided in Figure 4 below.

![Figure 4. Results of the FCI](image)

There is no significant difference between pedagogic approaches at the first take. Then, both methods of learning produce, in average, an improvement of results. However, when looked in detail, the effects of the methods appear to be contrasted. There are negative gains, (i.e. lower results after the learning session), up to seven points, in both modalities (TT and PBL). Positive gains seem to be more important with Problem-Based Learning. Again, the situation is contrasted: the analysis of variance shows that there are no significant discrepancies at the pre-tests. There are significant discrepancies at the post test in both senses in two centres: there are in favor of TT at Nanterre, and in favor of PBL in Pau.

These results will be discussed in the final conclusion, taking into account qualitative data.

**Quantitative results: the MBT**

The MBT test was designed by the same authors as the FCI. For their authors, FCI concerns everybody and allows determining the “preconceptions” in Mechanics. The MBT makes sense only for persons having attended a course in Mechanics and having learned equations and calculations. For the authors, the two tests are complementary. In the presentation of our results, the Problem-Based Learning group is noted PBL and the traditional teaching group is noted TT. Results are presented in Figure 5 below.
Figure 5. Results of the MBT

The results of this test are relatively weak, the global mean being 8.46 out of 26. There are significant discrepancies between the PBL group and the TT group in Pau at the pre-test, the PBL group having higher scores. The discrepancies are reduced after the course, with an average lower score for the PBL group. Nevertheless, the mean of the PBL group remains higher than the one of the TT group. Similarly, the PBL group of Nanterre has slightly higher scores than those of the TT group at the pre-test, but this mean is one point lower at the post-test, while the mean of the TT group increases slightly. In Saint-Nazaire, the PBL group also has higher scores than the TT group at the pre-test. It increases slightly at the post-test, but the TT group scores increase more and have their mean higher than the one of the PBL group at the post-test.

These results will be discussed in the final conclusion taking into account qualitative data.

Qualitative results

The experimentation of the PBL approach in Mechanics was followed by two students of the Master in Educational Sciences of the University Paris Ouest – Nanterre. One, in the first year, was interested in the cognitive effects of PBL approach (Vicherat, 2011), the other, in the second year, in the forms of collective learning in PBL situations (Gandon, 2011). Both students worked on the site of Nanterre. The qualitative data they have collected that will be used by us are of two types: observations during the PBL sessions and interviews of students.

These observations and interviews showed that experimentation had been perturbed by a lack of preparation of the students. PBL method destabilized the students because this approach requires from them an investment more important and more personal work than the traditional teaching. Some extracts of the interviews below reveal it clearly:

“I have done nothing, this system discouraged me!”

“I adhere in no way to this method – I don’t feel having learned that much! […] Personally, I need a structured course with exercises.”

Some students kept a critical attitude all the year-long, others changed their mind and admit some advantages in favor of the PBL approach.

“With PBL, it’s like to be immersed into a firm. Tools are given to us and then we have to manage by ourselves for learning. It’s up to us to use them in order to get the final solution.”

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Difference noticed between the results of the center of Nanterre and of the centers of Pau and Saint-Nazaire can be explained by the negative attitudes of some students.

Furthermore, differences in the attitude of the tutors were noticed. Some tutors refused categorically to answer the questions of the students while others gave some hints and help the students to find the response by themselves.

**Discussion and conclusions**

Sometimes, significant discrepancies between centres or between groups having followed different approaches appear, sometimes not. These discrepancies are summarized in the table below (Table 1).

**Table 1. Summary of Discrepancies (centres and methods)**

<table>
<thead>
<tr>
<th>Variability / Pedagogy</th>
<th>Variability / centre</th>
<th>Inter-centres</th>
<th>Intra-centre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nantes</td>
<td>St Nazaire</td>
</tr>
<tr>
<td>FCI</td>
<td>Pre-test</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>MBT</td>
<td>Pre-test</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Exams</td>
<td>Statics</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Kinematics and Dynamics</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

In view of this table, there is an influence of the center on the results of the post-test MBT and on the exam on Kinematics and Dynamics. While groups are homogeneous in terms of results at the FCI, discrepancies are significant for the MBT. The FCI requires physical reasoning while the MBT requires calculations, which are not easy to do under the conditions in which the test is taken. Besides that, the MBT exercises are very different from those seen during the course or the PBL sessions. This might explain the bad results of this test.

For the exam in Kinematics and Dynamics, discrepancies between centers can be explained by the fact that the examiners in each center are different (for example, the percentage of “A” marks varies from 35.89% in Saint-Nazaire to 1.78% in Pau). If the Rubrics grid seems to be objective and independent of the examiner, a debate between the examiners showed that the learning objectives must be clearly indicated for each question in order to avoid differences in evaluation.

Concerning the influence of the pedagogic method, our initial hypothesis was that this method doesn’t have an influence on knowledge acquisition, but can have an influence on conceptualization. Current results do not allow either validating or invalidating this hypothesis, since the results are different, depending upon the centre. Therefore, other factors than the pedagogic method have to be taken into account, and in particular the acceptance of PBL by students, and their feeling that their participating in an experiment is, for them, a kind of institutional mischief which could lead them to bad results at the end of the year!

This experimentation also allowed us to define axes of improvement. For example, since the students were destabilized by the PBL approach, it appears therefore necessary to prepare them by a first session, prior to the Harmonization module. It can also be necessary, in order to make the students more familiar with the approach, to extend it to other scientific domains such as electromagnetism and thermodynamics.

Our research also showed the necessity to respond to the claim of the students for having exercises to solve. This is why workshops (series of exercises) will be added during the SRA sequences.

Finally, to progress in the understanding of the effects of pedagogical methods on the process of learning, which have not only a cognitive dimension but also a conative dimension (Cosnefroy, 2011), the next step would be to study the feeling of self-efficacy and the factors influencing students’ motivation for PBL during the next phase of our experimentation.
References


WCPE 2012, Istanbul, Turkey
Computer Models Design for Teaching and Learning using Easy Java Simulation

Loo Kang Lawrence WEE, Ministry of Education, Education Technology Division (ETD), Singapore
Ai Phing LIM, Ministry of Education, River Valley High School (RVHS), Singapore
Khoon Song Aloysius GOH, Ministry of Education, Anderson Junior College (AJC), Singapore
Sze Yee LYE, Ministry of Education, Education Technology Division (ETD), Singapore
Tat Leong LEE, Ministry of Education, River Valley High School (RVHS), Singapore
Weiming XU, Ministry of Education, River Valley High School (RVHS), Singapore
Giam Hwee Jimmy GOH, Ministry of Education, Yishun Junior College (YJC), Singapore
Chee Wah ONG, Ministry of Education, Innova Junior College (IJC), Singapore
Soo Kok NG, Ministry of Education, Innova Junior College (IJC), Singapore
Ee-Peow LIM, Ministry of Education, Anderson Junior College (AJC), Singapore
Chew Ling LIM, Ministry of Education, Serangoon Junior College (SRJC), Singapore
Wee Leng Joshua YEO, Ministry of Education, Serangoon Junior College (SRJC), Singapore
Matthew ONG, Ministry of Education, Education Technology Division (ETD), Singapore
Kenneth Y T LIM, National Institute of Education, Nanyang Technological University, Singapore

Abstract

We are teachers who have benefited from the Open Source Physics (Brown, 2012; Christian, 2010; Esquembre, 2012) community's work and we would like to share some of the computer models and lesson packages that we have designed and implemented in five schools grade 11 to 12 classes. In a ground-up teacher-leadership (MOE, 2010) approach, we came together to learn, advancing the professionalism (MOE, 2009) of physics educators and improve students' learning experiences through suitable blend (Jaakkola, 2012) of real equipment and computer models where appropriate. We will share computer models that we have remixed from existing library of computer models into suitable learning environments for inquiry of physics customized (Wee & Mak, 2009) for the Advanced Level Physics syllabus (SEAB, 2010, 2012). We hope other teachers would find these computer models useful and remix them to suit their own context, design better learning activities and share them to benefit all humankind, becoming citizens for the world. This is an eduLab (MOE, 2012b; Wee, 2010) project funded by the National Research Fund (NRF) Singapore and Ministry of Education (MOE) Singapore.

Keyword: Blended Learning, Simulations, Computer Models, Open Source Physics, Teacher Education, teacher professional development, Easy Java Simulations active learning, education, e-learning, applet, design, GCE Advance Level physics

PACS: 01.50.H- 91.10.-v 96.20.Jz 04.80.-y 96.20.Jz

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Table 1. Summary of schools leading in the research and implementation of the lessons with computer model

<table>
<thead>
<tr>
<th>Lead school</th>
<th>Customized computer model</th>
<th>Original model author and sub-author codes*</th>
<th>Figure</th>
<th>Number of teachers</th>
<th>Number of students</th>
<th>Scaling up in other schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVHS</td>
<td>Collision carts (ideal)</td>
<td>Francisco Esquembre, Fu-Kwun Hwang*</td>
<td>1</td>
<td>3</td>
<td>242</td>
<td>SRJC, IJC</td>
</tr>
<tr>
<td>AJC</td>
<td>Collision carts (realistic)</td>
<td>Francisco Esquembre, Fu-Kwun Hwang*, Andrew Duffy*</td>
<td>2</td>
<td>3</td>
<td>67</td>
<td>On going</td>
</tr>
<tr>
<td>AJC</td>
<td>Falling magnet through solenoid</td>
<td>Francisco Esquembre</td>
<td>3</td>
<td>8</td>
<td>198</td>
<td>RVHS, SRJC</td>
</tr>
<tr>
<td>IJC</td>
<td>Ripple tank</td>
<td>Andrew Duffy, Juan Aguirregabiria*, Fu-Kwun Hwang*</td>
<td>4</td>
<td>5</td>
<td>77</td>
<td>YJC, RVHS</td>
</tr>
<tr>
<td>YJC</td>
<td>Geostationary orbit</td>
<td>Francisco Esquembre, Fu-Kwun Hwang*</td>
<td>5</td>
<td></td>
<td>250</td>
<td>On going</td>
</tr>
<tr>
<td>Field strength &amp; potential</td>
<td>Andrew Duffy, Fu-Kwun Hwang*</td>
<td>6</td>
<td>6</td>
<td>250</td>
<td>On going</td>
<td></td>
</tr>
<tr>
<td>Earth-Moon</td>
<td>Andrew Duffy, Fu-Kwun Hwang*</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kepler’s 3rd law</td>
<td>Todd Timberlake</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRJC</td>
<td>Superposition waves</td>
<td>Wolfgang Christian, Fu-Kwun Hwang*</td>
<td>9</td>
<td>7</td>
<td>145</td>
<td>On going</td>
</tr>
</tbody>
</table>

Introduction

We use a free authoring toolkit called Easy Java Simulation (EJS) (Esquembre, 2012) that allows ordinary teachers to create computer models as tools for interactive engagement (Adegoke, 2012; Hake, 1998) in physics education.

Building on open source codes shared by the Open Source Physics (OSP) community, and with help from the OSP community such as Fu-Kwun’s NTNUJAVA Virtual Physics Laboratory (Hwang, 2010), we customized several Easy Java Simulation (EJS) computer models (Figure 1 to 9) that we hope many teachers will find useful. They are all downloadable and free to redistribute and use under creative commons attribution licenses from Digital Library in NTNUJAVA Virtual Physics Laboratory (Hwang, 2010) and our working Google site https://sites.google.com/site/lookang/.

In chronological order of implementation of the lessons, these are the lessons with computer models that we have used to interactively engage (Hake, 1998) our students, making physics come ‘alive’ and learn through meaningful play (Lee, 2012).

Aligned to our goal of scaling up (Dede, 2007) meaningful use of information and communications technology (ICT) into curriculum, assessment and pedagogy (MOE, 2008) we would briefly describe Figure 1 to 9 on these computer models. These computer models can be used and further customized (Wee & Mak, 2009) as scientific inquiry tools, suiting teachers’ own “particular interests and educational points of view, and combine the use of a correct pedagogical approach with the sense of giving to it their own flavor” (Esquembre, 2002).
Collision carts (ideal) model (Wee, 2012b; Wee & Esquembre, 2008) derived from Francisco’s original work (Esquembre, 2009) showing mathematical representations to illicit predictive thinking about the concepts.

Collision carts (realistic) model (Wee, Esquembre, & Lye, 2012) derived from Francisco’s original work (Esquembre, 2009) with 3 scientific graphs showing realistic spring modelled during collisions

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Falling magnet through solenoid model (Wee, Esquembre, & Lee, 2012) derived from Francisco's original work (Esquembre, 2010b) showing a long solenoid show and the resultant induced voltage as the short bar magnet falls through.

Ripple tank model (Wee, Duffy, Aguirregabiria, & Hwang, 2012) derived from Andrew's original work (Duffy, 2010) showing pen paper representation of crest and scalar field display of the interference pattern due to 2 point sources S1 and S2.
Geostationary orbit model (Wee, 2012a; Wee & Esquembre, 2010) derived from Francisco’s original work (Esquembre, 2010a) showing a geostationary orbit (red) and a polar orbit (white).

Two mass model (Wee, Duffy, & Hwang, 2012a) derived from Andrew’s original work (Duffy, 2009) showing a 2 mass system with gravitational and potential lines in 1 dimension.
Earth-Moon model (Wee, Duffy, & Hwang, 2012b) derived from Andrew’s original work (Duffy, 2009) showing a 1 dimensional realistic model of the moon and earth system useful for exploring escape velocity concept.

Kepler’s 3rd Law system model (Timberlake & Wee, 2011) derived from Todd’s original work (Timberlake, 2010) showing earth and mars and their orbital trails for data collection of periods of planets.
Superposition of waves model (Wee, Christian, & Hwang, 2009) derived from Christian’s original work (Christian, 2008) showing 2 functions and their resultant (red).

II. Methods

Table 2. Research methods used by school River Valley High School (RVHS) and Anderson Junior College (AJC)

<table>
<thead>
<tr>
<th>School</th>
<th>Research Method</th>
<th>Students in experimental group</th>
<th>Students in control group</th>
<th>Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVHS</td>
<td>Lesson study</td>
<td>242</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>AJC</td>
<td>Experimental with pre-post test analysis</td>
<td>67</td>
<td>62</td>
<td>3</td>
</tr>
</tbody>
</table>

A. RVHS

1) Setup

The students are seated in groups of 3 to 4 and are equipped with the worksheet and a laptop loaded with the computer model (Wee, 2012b; Wee & Esquembre, 2008). The questions in the worksheet were adapted from the Newtonian Tasks Inspired by Physics Education Research by Curtis J. Hieggelke, to suit the particular interest of the teachers, curriculum and the language of local students.

2) Worksheet

The worksheet (VI Appendix A) uses open ended scenarios of the 3 different collisions with lesson design influenced by predict-observe-explain (Liew & Treagust, 1995) strategy, to allow students to discuss and collaboratively decide on the most appropriate answers to consolidate and extend their understanding that can be simulated using the computer model.
3) Limitation of study

Using the lesson study approach, limitations of the study include reliance on teachers’ subjective observation and difficulties in reviewing the large amount of video footage of the lesson.

B. AJC

1) Setup

Lesson classroom seating arrangement in AJC. Each student uses a personal laptop with the Collision carts (realistic) computer model aided with inquiry worksheet questions modified from Physics by Inquiry (McDermott, Shaffer, & Rosenquist, 1995)

The students are seated in groups of five and are equipped with the worksheet and a laptop loaded with the computer model (Wee, Esquembre, & Lye, 2012). The inquiry questions in the worksheet were adapted from the Physics by Inquiry (PBI) questions (McDermott, et al., 1995), to suit the content of local curriculum and language.

2) Worksheet

The worksheet (VII Appendix B) context of 2 gliders aims to promote conceptualization of Newton’s First Law (uniform motion in frictionless surfaces) and Newton’s Third Law of Motion (varying contact forces present during collision only, equal and opposite and on different bodies).

The worksheet focuses only on the example of collision of gliders and pre-post test questions are designed to lead students to conceptualize the same Newton’s Three Laws in multiple representations (Wong, Sng, Ng, & Wee, 2011). Students are asked to interpret the $f$-$t$ and $p$-$t$ graph. They are also required to draw vector diagrams of forces acting on the gliders at different instants. The questions in the worksheet aim to improve student’s mental construction of concepts and the process of knowledge construction is the focus of the lesson, guided by teacher facilitated discussion.

3) Limitation of study

Using the classical pre-test post-test research approach, limitations of the study include students not completing the pre/post-test to their abilities and inability to randomly divide into equivalent groups as classes are already pre-defined by school practices.
III. Data and Findings

A. RVHS

Some other teachers went into the classroom to study the lesson and these are some of their observations. We include excerpts of the lesson study notes by the teachers to give some themes and insights into the conditions and processes during the laboratory lessons.

1) Need for well scaffolded inquiry activities

“Students have difficulty because there weren’t enough info given, no masses, no velocities. Not used to such open cases (tutorials – all open and shut cases).”

2) Computer model can support inquiry activities

“Students are not easily convinced that two moving objects colliding together come to a complete stop.”

“(TH, YS and B) When faced with 2 contrasting theories, the more vocal or confident but wrong student (TH) was able to convince the other student (YS) of his answer. After the simulation, both appeared to quickly come to the right conclusion.”

“They did not return to the previous wrong answer to look at why it was wrong. Once the answer is revealed, students tend to just focus on theories which fit the answers; regardless of their own feel that they feel something is wrong.”

B. AJC

Table 3. Experimental and control group comparison, where ↑ 0 ↓ represents improved, no change and deteriorated in post test scores respectively.

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of students participated</td>
<td>62</td>
<td>67</td>
</tr>
<tr>
<td>No. of students used in &lt;g&gt;</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>No. of students who improved</td>
<td>44</td>
<td>41</td>
</tr>
<tr>
<td>Average Pre test score</td>
<td>6.03 ± 2.31</td>
<td>6.74 ± 2.10</td>
</tr>
<tr>
<td>Max = 11 marks</td>
<td>7.60 ± 2.26</td>
<td>7.69 ± 1.83</td>
</tr>
<tr>
<td>Average Post test score</td>
<td>↑ 0 ↓ ↑ 0 ↓</td>
<td></td>
</tr>
<tr>
<td>Newton’s First law</td>
<td>55% 25% 20%</td>
<td>32% 35% 33%</td>
</tr>
<tr>
<td>Newton’s Third law</td>
<td>60% 20% 20%</td>
<td>60% 30% 10%</td>
</tr>
<tr>
<td>% of students improved</td>
<td>71% 61%</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 suggests a higher percentage (55%) of students in the experimental group improved in the Newton’s 1st Law than control group 32% while a fairly equivalent number of students improved in Newton’s 3rd Law. Overall, the percentage of students that improved is (71- 61) = 10% higher in the experimental group compared to the control group. The increase in post-pre test scores is higher (1.56 ± 2.93 vs 0.95 ± 1.78) but the post scores are fairly equivalent (7.60 ± 2.26 and 7.69 ± 1.83). The standardized mean difference of the experimental over the control group is 1.56−0.95 = 0.21 which is medium in effect.

The average test scores in percentage (Figure 11) suggest higher score in Newton’s 1st Law as well.
Figure 11. Average test scores in percentage of the 11 marks pre-post test with newton 1st law and 3rd law and total scores

Using pre-test scores plotted versus normalized gains (Figure 12), the trend of higher normalized gains $g = \frac{\%_{post} - \%_{pre}}{100 - \%_{pre}}$ across 0 to 7 out of maximum 11 marks range of pre-test scores for the experimental group the emerged as well.

Figure 12. Graph of pre-test scores of both experimental (N=45) and control (N=45) groups versus hake’s normalized gain $g = \frac{\%_{post} - \%_{pre}}{100 - \%_{pre}}$ of students for the maximum scores of 11 marks with marks 8 to 11 omitted from analysis due to negative hake’s gain but it does not adversely affect the overall trend.

IV. Discussions

A. RVHS

We include excerpts from the qualitative survey results and informal interviews with the students to give some themes and insights into the conditions and processes during the laboratory lessons. Words in brackets $<$ > are added to improve the readability of the qualitative interviews.

1) Active and interactive engagement is key to learning

“I felt good learning this way because it facilitated and encouraged discussion in groups, and ultimately allowing us to have deeper impression of certain concepts. It was a good experience and I feel I gained more from this lesson than from regular <less interactive> classes. I feel that students should be given the link to download the tool after lessons for interactive learning even at home, because this gives students a more interesting way to revise certain topics”.

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“The lesson was one of the best methods to actually be able to experiment and witness firsthand the results of different kinds of collision and is thus pretty good.”

“I think we need more demonstration videos or java programs because people like me are visual learners and an animation will make learning clearer.”

1) Need good computer model design

“The computer model design was brilliant and I enjoyed and understood the concept better with it.”

“The applet provided an easy to understand interface and allowed for immediate understanding.

2) Need stronger scaffolds at the beginning of lesson

“The teachers should use the program to demonstrate and explain at the same time. Not letting us explore, and “wonder around”.

“Explain the concepts first.”

“It only feels good when our prediction and observations matched. Otherwise we were most of the time confused.”

A. AJC

1) Hake’s Gain and the rationale for removing data with high pre-test

Several students in both groups obtained negative Hake’s gain i.e. scored lower in the post test. We removed these students from the Hake’s gain analysis because of several reasons.

a) increased Hake’s gain sensitivity at higher pre-test scores

We speculate the increased sensitivity at higher pre-test scores say 8 marks, to score say lower say, 6 marks, which is computed as \( \frac{6-6}{11-6} = -200\% \), raised concerns about the validity of the test questions and students attitudes towards completing the tests.

b) Students making wild guesses during post test

We speculate some students are making wild guess during the post tests suggested from interviews and absurdly short quiz time clocked online and perhaps also the lack of challenge from same questions in pre-post test.

Thus, marks 8 to 11 (Figure 12) were omitted from analysis resulting in our Hake’s gain \( g \) analysis from 0 to 7 marks.

Although the Hake’s gains \( g \) for the various pre test scores are plotted and a general trend emerged from the data that suggests Hake’s gains of the students in the Experimental group are higher than the control group, from the linear fit (Figure 12) line.

Thus, with both medium effect standardized mean difference of 0.21 from experimental (N=62) and control (N=67) groups and the normalized gain analysis of the trend lines experimental (N=45) and control (N=45) groups and triangulated with interviews with students and teachers, the evidences suggest students did benefit from the experimental inquiry based lesson achieving deeper learning than their peers in traditional less interactive classrooms.

V. Conclusions

The 9 computer models derived from the Open Source Physics digital library are shared briefly giving credits to the original authors and sub-authors, so that ordinary teachers like us are able to stand on the shoulder of OSP giants and further customize our computer models to suit own syllabus and learning context.
A. RVHS
General feedback from students and teachers has been relatively positive, thus the teachers will be scaling up (Dede, 2007) the use of other computer models with sound pedagogical approach.

B) AJC
A medium effect of standardized mean difference of 0.21 from experimental (N=62) and control (N=67) and the higher normalized gain analysis from experimental (N=45) and control (N=45) across pre-test scores suggests that students who have benefitted from the inquiry based lesson can achieve deeper learning than their peers in traditional classrooms. In addition, general feedback from the students has been relatively positive, triangulated from students’ survey and focus group interviews, reflections by teachers.

We hope more teachers will find the simulation useful in their own classes and further customized them so that others can act more intelligible (Juuti & Lavonen, 2006) with them, benefiting all humankind, becoming citizens for the world.

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Any opinions, findings, conclusions or recommendations expressed in this paper, are those of the authors and do not necessarily reflect the views of the MOE, NIE or NRF.

Reference


WCPE 2012, Istanbul, Turkey

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<table>
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<tr>
<th>AUTHOR</th>
<th>BIO</th>
</tr>
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<tbody>
<tr>
<td><strong>Loo Kang Lawrence WEE</strong> is currently an educational technology specialist at the Ministry of Education, Singapore. He was a junior college physics lecturer and his research interest is in Open Source Physics tools like Easy Java Simulation for designing computer models and use of Tracker.</td>
<td></td>
</tr>
<tr>
<td><strong>Ai Phing LIM</strong> is currently a teacher in River Valley High School, Singapore. She has over 14 years of teaching grade 11 and 12 experience and has Masters in Science Education.</td>
<td></td>
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<tr>
<td><strong>Khoon Song Aloysius GOH</strong> is currently a physics teacher in Anderson Junior College. His academic and professional interests include the appropriate use of ICT to enhance learning and feasibility of organization management theories in Singapore’s public school system.</td>
<td></td>
</tr>
<tr>
<td><strong>Sze Yee</strong> is currently an educational technology officer in Ministry of Education, Singapore. She is a trained Physics Teacher and had taught both Physics and science in secondary and primary schools. She is now working on modifying the Open Source Physics Simulations for physics-related topics in primary school.</td>
<td></td>
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<tr>
<td><strong>Tat Leong LEE</strong> is currently the Head of Department for Education Technology in River Valley High School, Singapore. He is a high school Physics teacher, with 10 years of teaching experience. He has been using Open Source Physics (OSP) tools as early as 2006 (Tracker and Easy Java Simulations).</td>
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<td><img src="image1.jpg" alt="Image" /></td>
<td>Weiming XU is currently the Acting Subject Head for Educational Technology in River Valley High School, Singapore. He is a high school Physics teacher with a passion and interest in integrating multiple modes of representation of information in the teaching of Physics to provide authentic and meaningful learning experiences.</td>
</tr>
<tr>
<td><img src="image2.jpg" alt="Image" /></td>
<td>Giam Hwee Jimmy GOH is currently the Head of Science Department in Yishun Junior College, Singapore. He teaches Physics to both year 1 and 2 students at the college and advocates inquiry-based science teaching and learning through effective and efficient means.</td>
</tr>
<tr>
<td><img src="image3.jpg" alt="Image" /></td>
<td>Chee Wah ONG is currently a senior teacher teaching in Innova Junior College, Singapore. He has over 16 years of experience teaching grade 11 and 12 and has a Master degree in Science.</td>
</tr>
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<td><img src="image4.jpg" alt="Image" /></td>
<td>Soo Kok, NG is currently teaching in Innova Junior College. He has 23 years of teaching experience and a keen advocate of experiential learning.</td>
</tr>
<tr>
<td><img src="image5.jpg" alt="Image" /></td>
<td>Ee Peow LIM is currently teaching in Anderson Junior College, Singapore. He is leading a Physics ICT Resource Team of teachers. Before that, he obtained a distinction in pre-service teaching practicum with his creative teach methods.</td>
</tr>
<tr>
<td><strong>Chew Ling Lim</strong> is currently teaching Physics at Serangoon Junior College, Singapore. She has 7 years of teaching experience.</td>
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<td><strong>Wee Leng Joshua Yeo</strong> is currently teaching Physics at Serangoon Junior College, Singapore. He is also one of the College’s ICT Mentor spearheading the initiative to create a critical mass of teacher advocates or champions to develop and cascade effective ICT practices.</td>
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<tr>
<td><strong>Matthew Ong</strong> is currently an educational technology officer in Ministry of Education, Singapore. He has experience teaching in the grade 1 to 6.</td>
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<tr>
<td><strong>Kenneth Y T Lim</strong> is a Research Scientist at the Office of Education Research, National Institute of Education. His present research interests are in the affordances for learning that immersive environments offer. Through his research, he is developing a theory of learning around the concept of Disciplinary Intuitions.</td>
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VI. Appendix A: Worksheet with suggested answers by RVHS

Subject: Physics
Time: 1h 15 min

Level: A-Level

Worksheet Title: P06 – Collisions between two bodies – Virtual Laboratory

Apparatus List

01 × laptop

In this practical you will investigate the dynamics of collisions with TIPERs worksheets using the easy Java simulation ejs_users_sgeducation_lookang_Momentum1D2010web02.jar.

The following sections consist of various collision scenarios.

Read through the context carefully before making an educated guess as to the outcome. Explain your reasoning.

Finally, run the simulation to verify your prediction.

Are your predicted outcome and the simulated outcome identical? If they are not, explain the discrepancy.

How to use the Virtual Laboratory

Select the type of collision by clicking the radiobutton.

Key in the masses of the cart 1 and press the enter key. Repeat for cart 2

Key in the initial velocity of cart 1 and press the enter key. Repeat for cart 2.

Click the play button to start the simulation.

Reset the simulation by clicking on reset button.

You may wish to explore other features such as graphs in your own free time.

E.g.: \( e \) is the coefficient of restitution and it is the ratio of speeds after and before an impact, taken along the line of the impact (i.e. a measure of how much kinetic energy is lost).

(a) Carts A and B are shown just before they collide.

\[
\begin{align*}
&3 \text{ m/s} & &4 \text{ m/s} \\
&4 \text{ kg} & &3 \text{ kg} \\
\end{align*}
\]

Cart A

Cart B

No other information is given. Don’t Ask. ☺

Four students discussing this situation make the following contentions:
Eugene: “After the collision, the carts will stick together and move off to the left. Cart B has more speed, and its speed is going to determine which cart dominates in the collision.”

Sean: “I think they’ll stick together and move off to the right because Cart A is heavier. It’s like when a heavy truck hits a car: The truck is going to win no matter which one’s going fastest, just because it’s heavier.”

Thomas: “I think the speed and the mass compensate, and the carts are going to be at rest after the collision.”

Meili: “The carts must have the same momentum after the collision as before the collision, and the only way this is going to happen is if they keep the same speeds. All the collision does is change their directions, so that Cart A will be moving to the left at 3 m/s and Cart B will be moving to the right at 4 m/s.”

Which, if any, of these four students do you agree with?

Eugene _____ Sean _____ Thomas _____ Meili _____ None of them _____

Explain.

Answer: None of these contentions is correct. We do not have enough information to determine the velocity of either cart after the collision. Momentum will be conserved for the collision, but this could happen in a number of ways, such as the carts sticking together and remaining at rest, or the carts bouncing off one another. What actually happens depends on the construction of the carts and on the material of the surfaces that come into contact (rubber, clay, Velcro, etc.).

(b) Two identical carts traveling in opposite directions are shown just before they collide. The carts carry different loads and are initially travelling at different speeds. The carts stick together after the collision.

Three physics students discussing this situation make the following contentions:

Sherwin: “These carts will both be at rest after the collision since the initial momentum of the system is zero, and the final momentum has to be zero also.”

Sunny: “If that were true it would mean that they would have zero kinetic energy after the collision and that would violate conservation of energy. Since the right-hand cart has more kinetic energy, the combined carts will be moving slowly to the left after the collision.”

Steven: “I think that after the collision the pair of carts will be traveling left at 20 cm/s. That way conservation of momentum and conservation of energy are both satisfied.”

Which, if any, of these three students do you think is correct?

Sherwin _____ Sunny _____ Steven _____ None of them _____

Please explain your reasoning.
Answer: Sherwin is correct. The momentum of the two carts are equal and opposite before the collision, so the total initial momentum is zero and the total final momentum has to be zero also.

In Case A, a metal bullet penetrates a wooden block. In Case B, a rubber bullet with the same initial speed and mass bounces off an identical wooden block.

No other information is given. Don’t Ask. ☺

Will the speed of the wooden block after the collision be greater in Case A, greater in Case B, or the same in both cases?

Explain.

Answer: Greater for B. The initial momentum in both cases is the same and points to the right. The final momentum of the bullet points to the right in Case A and to the left in Case B. Since the final momentum of the system consisting of the bullet and the block is the same as the initial momentum, and this final momentum is the vector sum of the momentum of the bullet and the momentum of the block, the momentum of the block must be greater in Case B.

Will the speed of the bullet in Case B after the collision be greater than, less than, or the same as the speed of the bullet just before the collision?

Explain.
Answer: Less than. The energy of the system containing both block and bullet cannot be greater after the collision than before. The initial energy is the kinetic energy of the bullet, and the final energy is the sum of the kinetic energies of the bullet and the block. Since the block has a non-zero final kinetic energy, the final kinetic energy of the bullet must be less than the initial kinetic energy of the bullet.

Half Way Check Point

For each of the earlier situations (a) to (c), answer the following questions.

List all the external forces exerted on the system.

Does the system have an initial momentum? Describe any changes in its total momentum.

Does the system experience a net impulse during the specified time period? Explain.

(a) 1. Assume friction is negligible.

2. Initially, the system has zero momentum. The total momentum does not change with time. Or rather, the change in momentum is zero.

3. There is no net impulse delivered to the system. The gravitational and normal forces balance.

(b) 1. Assume friction is negligible.

2. Initially, the system has zero momentum. The total momentum does not change with time. Or rather, the change in momentum is zero.
3. There is no net impulse delivered to the system. The gravitational and normal forces balance.

(c) 1. Assume friction is negligible.

2. Initially, the system has momentum. The total momentum does not change with time. Or rather, the change in momentum is zero.

3. There is no net impulse delivered to the system. The gravitational force on the bullet causes a small vertical downward change in momentum of the bullet, which is negligible.

Extending Your Understanding

(e) Two identical steel balls, P and Q, are shown at the instant that they collide.

The paths and velocities of the two balls before and after the collision are indicated by the dashed lines and arrows.

The speeds of the balls are same before and after collision.

For the questions below, use the directions indicated by the arrows in the direction rosette, or use J for no direction, K for into the page, L for out of the page, or M if none of these are correct.

Which letter best represents the direction of the change in momentum for ball Q?

Answer: A. The change in velocity of ball Q is its final velocity minus its initial velocity, and is found by subtracting vectors as shown.

Which letter best represents the direction of the change in momentum for ball P?

Explain.
Choose the letter that best represents the direction of the initial momentum for the system of both balls P and Q before collision.

Explain.

Answer: C. The initial momentum of the system is the vector sum of the initial momentum of the individual balls. When added together, these momentum point to the right as shown.

Answer: C. The final momentum of the system is the vector sum of the final momentum of the individual balls. When added together, these momentum point to the right as shown. Note that since momentum is conserved for this system, the final momentum is equal to the initial momentum.

Choose the letter that best represents the direction of the final momentum for the system of both balls P and Q after collision.

Explain.

Answer: J. There is no direction since there is no impulse on the system during the interaction. There are no external forces, and so no impulse and no change in momentum for the system.

Appendix B: Worksheet with suggested answers by AJC

Experiment 1

Glider A is launched towards and collides inelastically with a stationary glider B on a smooth plane. After the collision, glider A reverses direction. The mass of glider A, m is one fifth the mass of glider B.

Given the conditions above, attempt the Java simulation with different values of initial velocities.
In the space provided, draw separate free-body diagrams for each glider and for the system S of the two gliders at an instant during the collision.

(B) How does the net force on glider A, FA, compare to the net force on glider B, FB, at this instant? Discuss both the magnitude and direction of the net force.

The magnitude of FA is greater than / equal to / smaller than the magnitude of FB.

The direction of FA is same as / opposite to the direction of FB.

(C) The F-t graph (Figure 1) below shows the net force FA acting on glider A during the collision. On Figure 1, sketch the variation with time t of net force FB acting on glider B.

(Figure 1)

(A) What can you say about the net force acting on glider B

(i) before collision zero
(ii) during collision FB (equal to FA)
(iii) after collision zero

Now, consider the time interval while the gliders are still in contact during the collision to be Δt. How does the product FA Δt compare to the product FB Δt? Discuss this in terms of the magnitude and direction.

Since FA equal to FB in magnitude and opposite in direction, FA Δt and FB Δt are equal in magnitude and opposite in direction.

Apply Newton’s second law (for constant mass) \( F_{\text{net}} = m \frac{\Delta v}{\Delta t} \) to each of the gliders to compare the change in momentum (Δp=mΔv) of gliders A and B during the collision. Discuss both the magnitude and direction of the change in momentum.
The magnitude of the change in momentum of glider A is greater than / equal to / smaller than the magnitude of the change in momentum of glider B.
The direction of the change in momentum of glider A is same as / opposite to the direction of the change in momentum of glider B.
The area under an F-t graph represents the change in momentum of a body. Hence, on Figure 2, sketch corresponding momentum-time graphs for

glider A

glider B

![Figure 2](image)

Describe the momentum-time graph for glider B after the collision.
The momentum-time graph for glider B after collision is a straight horizontal line.
Using your answers to D (iii) and H, what can you say about the velocity of glider B during this period?
The velocity of glider B during this period is constant. (No net force, no change in momentum)

Experiment 2

Glider A is now launched with a momentum of 200 kg m s⁻¹ towards glider C which is moving in the opposite direction with a momentum of 50 kg m s⁻¹. After the inelastic collision, glider A reverses direction. The mass of glider A is 25 kg and the mass of glider C is 40 kg. The coefficient of restitution e for this collision is 0.897.

(A) In the space provided, draw separate free-body diagrams for each glider and for the system S of the two gliders at an instant during the collision.

![Free-body diagrams](image)

How does the net force on glider A, FA, compare to the net force on glider C, FC, at this instant? Discuss both the magnitude and direction of the net force.
The magnitude of FA is greater than / equal to / smaller than the magnitude of FC.
The direction of FA is same as / opposite to the direction of FC.
Discuss the magnitude and direction of the change in momentum.
The magnitude of change in momentum of glider A is greater than / equal to / smaller than the magnitude of change in momentum of glider C.
The direction of change in momentum of glider A is same as / opposite to the direction of change in momentum of glider C.
Using values obtained from the Java simulation, fill in the final momentum of glider A and complete the momentum-time graph of glider C with an appropriate value.

\[ \text{final momentum of A} = -70 \text{ kg m s}^{-1} \]

**Thinking Questions**
Comment on the velocities of the bodies after they collide elastically for the following situations:
1. 2 identical masses colliding.
2. A tennis ball incident on a wall
3. A bowling ball incident on a stationary table tennis ball.

Use the Java simulation to confirm your results.

Adapted from Tutorials in Introductory Physics ©Prentice Hall, Inc.

WCPE 2012, Istanbul, Turkey
Attempts of Transforming Teacher Practice Through Professional Development

Vera Montalbano, Roberto Benedetti1, Emilio Mariotti1, Department of Physics, University of Siena, Siena, Italy
Maria Alessandra Mariotti, Department of Mathematics and Computer Science “R. Magari”, University of Siena, Siena, Italy
Antonella Porri, Regional Scholastic Office of Tuscany - Arezzo Territorial Area, Arezzo, Italy

Correspondence concerning this article should be addressed to Vera Montalbano, Department of Physics, University of Siena, via Roma 56, 53100 Siena, Italy.

Abstract

A difficult challenge in physics education is to design professional development programs for teachers, which can lead to fundamental changes in their practice. We report all activities for physics teachers in the context of the National Plan for Scientific Degrees in Southern Tuscany. Research and practice have shown that physics teaching in school is inadequate. The main consequences are limited achievements in school, decrease of students’ interests in learning physics and decrease of enrolments in physics in many countries. In recent years, the decline in enrolments was faced up with the launch of a wide national project addressed to secondary school students and teachers. The active involvement of teachers in the design of laboratories was found to be essential for obtaining actions which were not transitory and entered permanently in classroom practice. We describe some advanced courses in Physics and Mathematics Education realized few years ago and courses designed for a Master in Physics Educational Innovation and Orienting performed jointly by many Italian universities. Other activities are less formal but equally relevant, such as the active involvement of expert, young and in training teachers in designing and implementation of laboratory activities for a summer school of physics. Recently, we developed a workshop for teachers of physics and mathematics on modelling, which continued in an updating course for teachers in which selected topics, named in the same way in both disciplines, were discussed in order to design interdisciplinary learning paths. The purpose is to clarify these topics by using specific tools from physics and mathematics and to outline the similarities and the differences in both contexts. We believe that this activity can be useful for students, which can acquire a profound insight on selected fundamental concepts, and for teacher professional development. We describe teacher reactions and the more significant difficulties we encountered. Finally, we discuss which kind of activity seems more effective.

Keywords: continuous learning, teaching methods and strategies, professional development

The decline of interest in studying science is a serious concern for any society in which technology and science are essential in order to achieve an economic prosperity. In the past decades, an impressive decreasing of interest of young people in pursuing scientific careers was observed almost everywhere in the world (Czujko, 2002; Bucchi & Neresini, 2004; National Science Board, 2007; Convert, 2005; Mulvey & Nicholson, 2011). Furthermore, research indicated widespread scientific ignorance in the general populace (Durant & Bauer, 1997; Durant, Evans, & Thomas, 1989; Miller, Pardo, & Niwa, 1997). Then it is essential to educate in sciences as many students as possible to the highest level in the school for obtaining the goal of enhancing the scientific literacy and increasing the number of motivated and talented students enrolling in courses scientific degrees. The quality of teaching plays a crucial role in this context (Osborne, Simon, & Collins, 2003).

During the last decade, we realized several professional development programs for teachers in Physics and Mathematics in order to promote fundamental changes in their practice. Our activities were directed to teachers living in southern Tuscany (provinces of Arezzo, Grosseto and Siena).
In the beginning, we were concerned with teacher training in the Advanced School for Teaching in Secondary School of Tuscany (a 2-years post-graduated course required, at that time, for obtaining teaching qualification in Italy\(^1\)). Since almost all teachers (expert or in training) in our region are not physicists but rather mathematicians or engineers, a strong requirement arose: Put laboratory in the centre of physics education. Designing professional development programs for teachers, which can lead to fundamental changes in the quality of their teaching, was indispensable.

In the following, we present a survey of selected activities that we realized in recent years in order to transforming teacher practice through professional development. Since almost all activities were realized within the National Plan for Scientific Degrees, in the next section we present the plan focusing on the methodological choices which were transposed in the professional development programs for teachers. In the following one, we describe in details a selection of activities, focusing on teacher reactions and the more significant difficulties we encountered. In the last section, we discuss the obtained results and which type of activities appears more effective. In particular, the context in which the activity is realized seems to assume an important role.

Actions for Scientific Degrees in Italy

In recent decades it has been detected almost everywhere a consistent decrease of graduates in science disciplines. The situation in Italy was dramatic; enrolments in basic sciences are more than halved in few years (Vittorio, 2010). Therefore, the Ministry of Education and Scientific Research promoted a wide project in order to reverse this trend. Starting at the end of 2005, the project was named Scientific Degree Project (Progetto nazionale per le Lauree Scientifiche, i.e. PLS) and was financed for four years. During this period and at the end of the project, a large monitoring of all activities was realized in order to identify what actions were more effective and incisive in contrasting decreasing of scientific vocations. The main actions of PLS were professional development for teachers and orienting for students essentially by means of laboratory activities (see for example Sassi, Chieferi, Lombardi, & Testa, 2012). In 2009 it was launched the National Plan for Science Degree (same acronym PLS) where some of the most effective methodological aspects were emphasized in new guidelines (PLS website; Vittorio, 2010).

Scientific Degree Project 2006 - 2009

The project originated from a collaboration of the Ministry of Education and Scientific Research, the National Conference of Deans of Science and Technology and Confindustria, the main organization representing Italian manufacturing and services companies, and was designed with the initial motivation to increase the number of students on degree courses in Chemistry, Physics, Mathematics and Science of Materials.

The project focused on three main objectives (Vittorio, 2010):

- improving knowledge and awareness of science in secondary school, offering students in the last three years of school to participate in stimulating and engaging curricular and extra curricular activities in laboratory;
- starting a process of professional development of science teachers in service in the secondary school from joint work between School and University for the design, implementation, documentation and evaluation of the laboratories mentioned above;
- promote alignment and optimization of training from University and School for the working world.

---

\(^1\) The Advanced Schools for Teaching in Secondary Schools became the only way for obtaining teaching qualification for teaching in schools of first and second degree. Activated in the Academic Year 1999-2000 with the cycle I, they were finally closed in the Academic Year 2008-2009 at the end of the ninth cycle. They were organized at inter-regional level, with closed number access (set each year by the Ministry of University and Research). Starting with the Academic Year 2012-2013, the teaching qualification can be achieved by following an annual course named Formative Active Training.

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The action for student integrated with training for teachers was made through more than 100 sub-projects under the responsibility of local referents, located in 33 universities, became 38 in the last period, spread all over the country and organized into four areas of national projects (PLS website; Vittorio 2010).

**National Plan for Science Degree 2010 - 2012**

The plan maintained the same purposes of increasing the enrolment in science degrees to which was added the necessity to revise the content and methods of teaching and learning of science in all grades of school, taking into account the new national guidelines for first and second cycle contained in the recent Italian reform of the educational system.

**Strategy and Methodologies**

In order to achieve the above purposes, the Plan pursued the strengthening and the practical realization of the main ideas that were effective in trials 2005-2009 (PLS website):

- orientation does not conceive how a teaching path given to student, but as an action that the student is doing, from meaningful activities that allow to compare problems, issues and ideas of science;
- designing the training of teachers in service by involving teachers in solving concrete problems, developing design and implementation of educational activities and through comparison with peers and experts;
- pursuing and achieving at the same time the student orientation and training for teachers through the planning and joint implementation by school teachers and university laboratories for students, thus developing relations between the school system and the University;

Furthermore, a new idea was added: consciously connecting the activities of the Plan with the innovation of curricula and teaching methods adopted in schools, and other contents and methods of teacher training (initial and in-service), for the first and second cycle. Thus, the main road consisted in considering laboratory as a method, not as a place. Students must have become the main character of learning and joint planning by teachers and university was a mandatory step.

More attention to laboratory is required and different types of laboratory PLS can be proposed: Laboratories which approach the discipline and develop vocations, Self-assessment laboratories for improving the standard required by graduate courses, Deepening laboratory for motivated and talented students (for a survey on PLS laboratories realized locally see Montalbano, 2012).

**Professional Development Programs in Southern Tuscany**

Since 2000, the Department of Physics is engaged in many activities with the purpose of enhancing cultural knowledge and skills of training and in-service teachers. First advanced course started in order to satisfy a request from young teachers for further examples of designing learning path in physics and mathematics after their teacher qualification in the Advanced School for Teaching in Secondary School of Tuscany. The experience was positive, the purpose and the methodology were very close to the PLS and therefore we decided to propose this course for the project. The social context, and national legislation continuously changes with respect to teaching, required that new proposals were designed almost every one or two years. In the following, these activities are briefly described focusing on the typology of participants, the effectiveness of the activity, encountered difficulties and achievements, and so on. The evaluation arose from observations during the activity and discussions performed at the end by all people, faculty staff and expert teachers, which were involved in the professional development program.

**Advanced Courses for Teachers of Physics and Mathematics**

Starting in 2004, we organized an annual advanced course for professional development of qualified teachers, entitled *Learning paths in Physics and Mathematics: Models, Experimental checks, Statistics*. Teachers were engaged in designing learning paths with particular attention to relationship between physics and mathematics.
Activity description. The main features of this program were a long period activity (100-125 hr spread over several months), compulsory attendance, a score for teacher ranking available after final examination, a huge period dedicated to activities in laboratory, data analysis and discussion on educational aspects. The activities were divided in two courses: Society and education (25-35 hr) and Educational Research Laboratory (75-90 hr).

Society and education. We presented educational resources that can be found outside the school (e.g. science museums, interactive science exhibitions), conferences on history of physics or mathematics, cultural reflections that can enrich the quality of teaching. When the conference was of more general interest it was open to public.

Educational research laboratory. Experts from school, university and research institutions presented innovative tools for education in three topics selected from the school curriculum. Small groups of teachers elaborated these topics, by designing and implementing learning paths in the laboratory and analysing experimental data. At the end, they produced materials in order to discuss some learning paths in the final examination. Some examples of proposed educational research laboratories are the following: Modelling and approximating in mathematics and physics, Wave phenomena, Educational project on modern physics, Introduction to relativity, Waves and oscillations: a methodological reflection, From electrical charge to Joule effect, Waves: from sound to light, From special to general relativity.

Participants. We proposed the advanced course for four academic years. Enrolments for each year are showed in Table 1. Few participants had a permanent position but all were teaching at school. The decreasing of enrolments corresponds to a change in rules for attributing score for teacher ranking and the proliferation of online courses that gave the same score with fewer costs and efforts for teachers.

Activity analysis. The goal of the advanced course was achieved. Participants selected, within all teaching suggestions, one or two ideas that were developed by preparing educational materials ready for the use in classroom and laboratory. Few teachers were able to test in their classes the learning path and evaluate its effectiveness. Moreover, we identified the following critical points:

- the course was very intensive for teachers;
- the most part of the participants were young teachers with no permanent position, thus with no possibility of engaging in long term experimentation or stable collaboration with colleagues of their schools. Thus, the possible impact of the intervention on school practice is limited.
- every year it became more difficult to organize the course (University taxes became too high);
- online course organized by private institutions gave the same score for teacher ranking with fewer costs, time engagement and effort for teachers.

Training in Pigelleto’s Summer School of Physics

Since 2005, forty students from high school are selected to attend a full immersion summer school of physics in the Pigelleto Natural Reserve, on the south east side of Mount Amiata in the province of Siena (Benedetti, Mariotti, Montalbano, & Porri, 2011). Perhaps, this is the most successful activity that we have ever realized in PLS for orienting students towards physics.

Starting from the third edition of the school, teachers enrolled in Advanced School for Teaching in Secondary School of Tuscany were invited for a stage at the summer school. After the closure of the Advanced School for Teaching in Secondary School, we still continue to invite young teachers for a full-immersion stage.

Activity description. The school begins usually in early September and lasts for four days. The 2011 edition was entitled Thousand and one energy: from sun to Fukushima; some previous editions were Light, colour, sky: how and why we see the world (2006), Store, convert, save, transfer, measure energy, and more… (2007), The achievements of modern physics (2009), Exploring the physics of materials (2010). Topics are chosen so that students are involved in activities rarely pursued in high school, relationships with society are outlined and discussed. The students are selected by their teachers in the network of schools involved.
in the National Plan for Science Degree [8]. In the morning, we propose lessons in which the necessary background for the following activities in laboratory is given. In the afternoon, small groups of students from different schools and classes are engaged in laboratories where are forced to take an active role. All groups are supported by one or two teachers that are available to discuss any idea. Usually we propose different laboratories and for each one the group of participants is asked to prepare a brief presentation for sharing with other students what they have learned. After dinner, an evening of astronomical observation of the sky is usually expected. If it is cloudy, a problem solving evening is proposed. In designing activities, we pay attention to several aspects that can render this action more effective both for teachers that for students, for example the main topic is related to all activities and must not be trivial. In order to have the best collaboration, students’ groups are inhomogeneous and formed by following the teachers suggestions. When it is possible, laboratories are made with poor materials or educational devices provided by a school in such way that teachers can duplicate easily the lab in their context. In order to focus student and teachers attention to physics as an experimental science, almost all laboratories lead to at least one measure and its error valuation. Last but not least, methodologies are discussed and selected with the teachers involvement and usually in laboratory an expert and a young teacher are engaged in order to improve teacher practise. Let us give some examples of laboratory: Measurement of Plank’s constant by a LED, Measure of the speed of rotation of a star, How it works: Stirling machine, solar oven, coffee pot, Measurement of the mechanical equivalent of heat, Electromagnetic induction and energy dissipation, Radioactivity background vs. small Uranium sources, Photoelectric effect.

Participants. Usually there are about 4-5 expert teachers and 5-7 young teachers. In the last edition some young teacher acquired enough experience to become expert.

Activity analysis. This informal training seems to be very effective. Young teachers benefit from direct experience in laboratory with expert teachers. Participants sometimes seem to be inspired by the school’s laboratories and some activities entered in practise. On the other side, we identified the following critical points:

- the summer school was very intensive for teachers and often they are obliged to interrupt the stage for going back to school service;
- young teachers (almost all with no permanent position) can be called for a temporary job during the school;
- teachers in-service almost never participate to the summer school (they usually prefer not to accompany their student).

Master in Physics Educational Innovation and Orienting

In recent years, a national master designed for qualified teachers has been organized by University of Udine. We joined the master’s third edition where nineteen universities all over the country collaborated for giving courses in laboratory, often focusing on laboratories performed within the National Plan (Stefanel et al., 2012)

Activity description. Participants can choose between a variety of courses. Many courses are online, but laboratories requiring presence must be taken in one of the universities. After few introductory lessons in which methodological and disciplinary aspects were treated usually by discussing as example a PLS laboratory, teachers were asked to design a specific learning path. When it was possible, paths were then tested in class. The courses given by University of Siena have been the following: Modern physics, Advanced physics experiments, Spectroscopy laboratory, Look at the universe: astrophysical observations and measurements, Waves and oscillations, Phenomenology of sound, Paths on thermal phenomena, Paths on electromagnetism, Exploratory lab on superconductivity. The master allows two years of attendance, a final thesis must be discussed as final examination. Teachers can attend full activities of master or, taking fewer courses, attend an advanced course or finally attend only few courses that can be certified.

Participants. Teachers all over the country enrolled. Locally, we had one teacher for the master and two for single courses.
Activity analysis. The master raised a higher standard for the professional development because many activities inspired physics educational research in teachers (see for example Di Renzoni, Frati, & Montalbano, 2011), especially on topics rarely touched in class or in laboratory. As in the case of advanced courses, we identified the following critical points:

- the master was too intensive for in-service teachers;
- only few young teachers (with no permanent position) enrolled; therefore, there was no possibility for a change in practice.

Laboratory on Modelling

Since in 2009 also the Department of Mathematics and Computer Science of University of Siena launches its plan, a workshop for teachers of physics and mathematics on modelling was performed in collaboration with Physics Plan.

Mathematics is frequently introduced as a set of tools and techniques for modelling real world situations and solve real-world problems (for a characterization of modelling in mathematics education, see 122 in Niss, 2003). Thus, the relationship between mathematics and other sciences, in particular with physics, becomes purely instrumental and user tends to learn how to utilize it without worrying about understanding how and why a specific mathematical tool is useful for achieving a goal.

Also in physics, modelling process is central and physicists tend to use modelling as a research tool. For a brief survey of models in physics and physics education see for example p. 256 in Angell, Kind, Henriksen, and Gattersrud (2008) and for a wider overview in contemporary science education see GIREP (2006).

If a learning path describes phenomena without accounting for the process that led to their quantitative description, the modelling process remains hidden. Sometimes this process has a long and complex history, which shows the presence of epistemological obstacles that required time and intellectual development to be overcome. We believe that the same problem might arise for students and it can be an opportunity for a deeper learning process. Thus, not taking into account the complexity of the modelling process that is the origin, the phenomenon and its mathematical description seem to be as distinct features, artificially glued, and therefore often fail to interact.

The aim of this laboratory was to try to re-establish the relationship of synergy between the description/explanation of the experience and the mathematical model to be taught, presenting students work activities (explorations and problems) centered on the process of modelling: (a) starting from a rough problem, (b) the emergence of hypotheses, (c) varying quantities with the purpose of obtaining all relevant relationships between variables.

Activity description. The laboratory was performed with teachers, mathematicians and physicists, and we encountered every month for a total of 20 hr. We started by proposing selected topics, that in the curricula appear named in the same way in both disciplines. A first discussion was devoted to identify the particular perspective from which the ‘same’ topic was considered in the two disciplines. The final objective was the interdisciplinary design of learning paths that could exploit the different perspectives to make student construct unified and richer conceptions. The purpose was to make a specific conception emerge from a laboratory experience and then find a formalization in physics and mathematics: outlining similarities and differences in both contexts. Rough problems are proposed in order to inspire learning paths in which a modelling process can arise and develop in the different disciplinary fields. Though we believe that this kind of activity can be proposed only for specific topics, we believe that it would be useful for students to have the opportunity of experiencing, at least in some cases, how the modelling process can develop, and consequently acquire a profound insight on some fundamental concepts. The experience of designing this type of didactic path has been of great value for teacher professional development. The introductory discussions, to which physicists and mathematicians contributed bringing their own different perspectives, faced the teachers with epistemological and cognitive problems that they had never foreseen.

Participants. In the beginning, there were about 10 teachers (2 with a permanent position in school), but at the end only 4 remained.

WCPE 2012, Istanbul, Turkey
Activity analysis. The activity was very stimulating for the participants but materials for the practice in class was slowly prepared after long discussions where the different cultural backgrounds of physicists and mathematicians involved emerged clearly. Only a couple of proposals were tested successfully in classroom. Because of the inter-disciplinary character of these kind of activities, it was difficult to experiment in the classroom, actually there are a few opportunity in this field in our schools. Moreover, we identified the following critical points, which we already find in other cases:

- meetings were too intensive for in-service teachers and there was an objective difficulty in conciliating the schedule of meetings with all teachers duties;
- again the most were young teachers (with no permanent position) limiting the possibility of sharing this experience with other colleagues. However, there was a great attention from some teachers in permanent position.

Thus, we decided to continue this experience the following year in an updating course for teachers in a school.

**Updating Courses for Teachers In-Service.**

**Overview.** Updating is compulsory for teachers in-service (6 hours every year), therefore there is a certain interest for teachers to follow updating courses that are really useful for their teaching practise. Different schools have different teams of teachers and different ways of perform the updating. Anyway, in these years we have tried to propose interesting and useful updating courses in order to improve teaching of physics and mathematics. The courses were often tailored on the specific context of the school where they were realized.

The nature of light: from classical physics to quantum physics. This course was performed in a scientific high school (Liceo Scientifico Statale *Redi* in Arezzo) in 2008/2009.

**Activity description.** For 10 afternoons we met participants in the physics laboratory of the school for a total of 40 hr. The first hour was dedicated to educational considerations on selected topics of physics, the rest of the time teachers were involved in performing experiments by using the facilities of the laboratory in the school.

**Participants.** There were 17 teachers enrolled, 13 of them regularly attended. The course was promoted in all schools in Arezzo and surroundings but the most of participants were in-service in that scientific high school.

**Activity analysis.** The activity worked very well. Teachers were all in-service and were strongly motivated in learning how to use their lab’s facilities because of the forthcoming reform of secondary school. Moreover, we got a strong school’s management support. Another important consideration is that the course was realized in a peculiar school, with very well furnished physics laboratory, but only few teachers were able to use this opportunity in their practice properly because their background was lacking in physics practise.

Course on physics laboratory in the new high schools. This course was performed in Liceo Scientifico Statale *Redi* in Arezzo in 2009/2010.

**Activity description.** For 8 afternoons we met participants in the school for a total of 24 hr. Teachers were interested in designing a meaningful curriculum for physics in a reformed school. They produced a detailed set of learning paths which covered the physics program for the first year of the reformed scientific high school.

**Participants.** There were 11 teachers enrolled that regularly attended the course.

**Activity analysis.** The activity was very satisfactory. Teachers were all in-service and are strongly motivated. There was again a strong school’s management support. Another aspect is that all teachers were in-service in that peculiar school.

Course on physics laboratory. The course was performed in a scientific high school (Liceo Scientifico Statale *Volta* in Colle Val d’Elsa, Siena) in 2009/2010, in order to satisfy a request from teachers in-service there.
Activity description. For 3 afternoons we met participants in the school for a total of 6 hr. Teachers were interested in performing some activity in their physics lab (few years ago the lab caught fire and all the surviving material remained unused). One of the authors (E. M.) went to find out what they had in their closets and then presented some learning paths in which teachers could use their supplies.

Participants. There were 6 teachers enrolled that had regularly attended the course.

Activity analysis. The activity was unsatisfactory. Teachers interested but not active They concerned only to obtain some useful hint for physics lab. Moreover, there was a weak school’s management support and all teachers were in-service in that school.

Mathematics and physics teaching in the reformed school. The course took place in Scientific High School (Liceo Scientifico Statale Galilei in Siena) in 2011/2012, in order to satisfy a request from teachers in Laboratory on modelling.

Activity description. For 10 afternoons we met participants in the school for a total of 30 hr. The methodology was introduced by some examples belonging from material elaborated in the Laboratory of modelling the previous year. Afterward, selected rough problems were proposed and participants realized a laboratory activity. The next step was to discuss together if the activities were effective or could be modified in order to achieve the goal of realizing an active process of modelling.

Participants. Despite 19 teachers enrolled, only 8 have regularly attended the course.

Activity analysis. The activity was unsatisfactory. Many teachers were interested only in obtaining some useful hint or ready recipe for physics lab, but they strongly opposed to challenge their way of teaching. Moreover, school’s management support was totally absent (only 2 participants were in-service in the school). The only positive aspect was that we started with few interested teachers a fully designing of interdisciplinary activities for the first year of the reformed scientific high school and for a technical school.

Discussion and Conclusions

Professional development is indispensable in order to obtain a real and permanent improvement of physics teaching. An active engagement of teachers in the design and implementation of learning paths closely related to laboratory activities is an essential step for trying to change the current teaching practice. Another key point is to experiment in the classroom or with groups of students the activities designed in order to clarify which ones are more effective and to increase the experience and confidence that teachers have in laboratory practices. The whole process from designing a didactic path to implementing it in a class is necessary for a teacher to develop the autonomy for innovation, based of a solid disciplinary background and a critical attitude towards educational issues.

Unfortunately, we found very difficult to involve actively in-service teachers, especially if they had a permanent position in school. At the origin of this difficulty, there is not only the intense engagement in school duties, but also a difficulty of changing well settled didactical habits, in spite of a general dissatisfaction in terms of learning achievements. Young teachers (often with no permanent positions) were more available to innovation and more disposed to invest their time to enhance their teaching skills. However, sometime the impact with the reality of the school makes them give up.

Updating courses are almost the only way to achieve teachers in-service (better if held in their school) and can be designed taking in account of the context. In this case, strong school’s management support is crucial in order to obtaining a wider teachers’ involvement.

Acknowledgement

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References


Poster Session Strand 3: Learning Physics Concepts, P2.G02.03

Stefanel, A., Michelini, M., Altamore, A., Bochicchio, M., Bonanno, A., De Ambrosis, A., ...


**Table 1**

<table>
<thead>
<tr>
<th>Qualified teachers enrolled in Advanced Course Learning paths in Physics and Mathematics</th>
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<tr>
<td>Academic year</td>
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<tr>
<td>Participants with permanent position</td>
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<tr>
<td>Participants without permanent position</td>
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<td>Total enrolments</td>
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SYMPOSIUM on
Teaching and Learning the Concept of Energy From Early Childhood School through University

Organizers:
Marisa Michelini, Research Unit in Physics Education, Department DCFA, University of Udine, Italy, marisa.michelini@uniud.it
Paula Heron, Department of Physics, University of Washington, USA, pheron@phys.washington.edu
Discussant: Lillian C. McDermott, Department of Physics, University of Washington, USA, lcmcd@phys.washington.edu

Abstract
The learning and teaching of energy has been a rich field for research among students ranging in age from elementary school through university. Many proposals for how to teach the subject have been guided by this research. In a Symposium at GIREP 2008 in Cyprus, several researchers presented findings with implications for teaching energy concepts. One outcome of the Symposium was the conclusion that no clear consensus exists on the structure of a vertically integrated curriculum for teaching energy. A Workshop was held at GIREP 2010 with the goal of making progress toward the challenge outlined above, specifically to make progress toward a unified, research-based view of which energy topics should be taught at which educational level. Since that time a Topical Group on Energy was formed within GIREP. In this symposia, researchers from Greece, Italy, Germany, the United States, Israel, Portugal and the Netherlands presented contributions on progress they have been making on the many problems associated with teaching and learning the concept of energy. Symposium speakers described their own investigations and place their findings within the context of the goals of the GIREP Working Group. Part I is focused on teaching energy to pupils in preschool and in primary school, as well as strategies for teacher formation. Part II examine the challenges of teaching the concept of energy to older pupils, in high school and university. Part III focused on the engaging students in thinking about energy issues in their own lives and the historical development of the concepts. After paper presentations the following colleagues participated to the rich discussion on learning problems and approaches on teaching / learning energy: ALMEIDA Maria, BESSON Ugo, CASTELS Marina, CHALLAPALLI Sri, CHIU WAI Chow, ELLERMEIJER Ton, CORNI Federico, HERNANDEZ Maria Isabel, HERRMANN Friedrich, HERON Paula, HOGLUND Jesper, KALTAKCI Derya, KESONEN Mikko, KOLIOPOULOS Dimitris, KONSTANTINIDON Katerina, LEHAVI Yaron, LEONE Matteo, LOPEZ Ramon, LETO Francesca, LOGMAN Paul, McDERMOTT Lillian, MICHELINI Marisa, OZCAN Hasan, POHLIG Michael, SCHILTZ Guillaume, STAMATIS Vokos, STASZEL Magdalena, SZCZYQIELSTA Aneta, URBAN WOLDRON Hildegard, YEN LING Lam.

In the following you will find the papers written by symposia contributors according with the three parts. An additional part include the poster contributions to the symposia. When the relative paper had been published we report the abstract of the presented paper.
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Part I
Teaching the Concept of Energy to Preschool and Primary School

Pupils and Teachers: Energy as a Context for Honing Formative Assessment and Inquiry Skills: Ivory Tower Meets Bazaar

Stamatis Vokos and Rachel Scherr, Physics Department, Seattle Pacific University, Seattle, WA, USA

Abstract

The Energy Project at Seattle Pacific University (EP) uses the conceptual framework of energy as a context for helping K-12 teachers grow in their roles as facilitators of authentic scientific discourse in the classroom. To make progress toward this goal, professional development of teachers has to attend to several important components. Deep content knowledge—understood here not as a set of facts and formulas but as an organized web of conceptual interrelationships—is absolutely necessary. So are knowledge of student ideas and the skills associated with noticing the disciplinary substance of these ideas, interpreting the cognitive or experiential needs of different students, understanding the big ideas related to the topic, and the flexible application of assessment strategies to monitor the moment-by-moment dynamics of these ideas. In the area of conceptual understanding, we have documented that a substance metaphor for energy (i.e., energy thought of as a “thing”—albeit massless and immaterial—that can be carried by objects and can flow among objects) is especially productive in helping to enforce energy conservation and to differentiate between the flow of energy and the flow of matter. We have introduced a class of novel energy transfer and transformation representations that keep track of energy flows dynamically and locally, as opposed to statically and holistically, thus making learners’ thinking more visible to themselves and others. We have also discovered through surveys, interviews, and workshops that students’ and teachers’ views of the nature of science, the nature of science teaching, and the real and perceived obstacles in adopting a student-centered environment influence greatly the extent to which rich classroom discourse may occur, regardless of the knowledge and skills of teachers in engaging in formative assessment.

Context for energy instruction

Energy is one of the crosscutting concepts in science education. It plays an indispensable role in scientific work. It also plays a defining role in geopolitical affairs and economic issues. Recognition of the multiple roles that energy plays animates societal expectations that our students will learn to represent the detailed story of energy transfers and transformations in everyday contexts that are relevant to science and their daily lives so as to be able to optimize systems to maximize “useful” energy transfers and minimize “unwanted” transfers.

And yet, energy instruction comes with special challenges. Energy is a very abstract concept, one that cannot be operationally defined (independently of its specific forms). It is also a concept that all scientific and engineering disciplines claim as their own yet think about in different, discipline-specific ways. Physicists, for instance, track the energy inputs and outputs of well-defined systems and rarely care about accounting for energy changes in the environment of those systems. Chemists often concern themselves more with concepts such as enthalpy and free energy than with energy itself. Biologists’ systems are defined in terms of some well-defined biological function. Physicists’ systems can be arbitrary collection of interacting or non-interacting objects. Earth scientists have to discuss open systems, in/out of which there is energy and mass transfer. And the list goes on...

Energy education, therefore, requires a coherent approach, which respects the disciplines’ richness and unique perspectives on one hand, yet provides a self-consistent description to the learners. The Energy Project at Seattle Pacific University seeks to provide such an approach.

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1 All science concepts are abstract in the sense that they are invented constructs of the human mind. However, most concepts can be operationally defined through well-defined, concrete operations. Energy, unfortunately, does not lend itself to an operational definition.

2 An energy analysis of a hurricane (admittedly not the easiest of contexts) illustrates the point forcefully.
**The Energy Project**


In this paper, we summarize the ways in which we address all four goals, with an emphasis on the first and last goal. The difference between the professional development environment (teachers as learners) and the precollege classroom (teachers as agents of change) is an important consideration. To foster free expression of student ideas, it is necessary to structure the classroom in a way that values such ideas and judges them on the basis of their productivity and their potential to lead to unambiguous predictions that agree with negotiated understandings thus far rather than on their initial alignment with the scientific canon, as understood by the teacher. In that light, we also discuss briefly results from a related project, the Qatar Science Teachers Energy Project (QSTEP)\(^2\), through which we have been able to document obstacles, real and perceived, in implementing a student-centered environment in a science education system that is focused on student and teacher accountability, implemented through standardized testing.

**Adopting a substance metaphor for energy**

We have discussed elsewhere different ontologies for energy and the representations that are aligned with them (Scherr, Close, McKagan, et al., 2012). Among such ontologies, we have found that the substance metaphor for energy serves our learning goals especially well. Let us illustrate the issue we face as educators by using as an example an elicitation question that was used in the very first session of a workshop for secondary physics and chemistry teachers in Doha, Qatar. The participants had been given batteries, connecting wires, switches, and flashlight bulbs and were asked to consider the following scenario using their firsthand observations. From the instant the switch closes until the brightness of the bulb reaches its maximum, there is a very short but noticeable time interval. What is the energy flow during that time interval? That is, where does the energy start? Where does it end up? Through which processes does it get there?\(^1\)

The teachers responded immediately addressing directly the facilitator, almost in unison and ignoring the request to discuss their thinking in small groups, “The chemical energy in the battery turns into light and heat in the bulb and heat in the wires and the battery.” The facilitator, anticipating this response, added the following. “Assume the chemical energy in the battery decreased by 20 units during this very short time interval. Follow these 20 units and come up with a representation that shows the complete story of the energy, including the time sequence of any transfers and transformations.” The room became silent and the teachers slowly started discussing with their peers this very different kind of energy conservation task. A group of teachers wondered about the effect of self-inductance in the circuit and the relative sizes of that effect and the effect of the non-instantaneous increase of the temperature of the bulb filament to its equilibrium temperature. Another group wondered about the sequence of energy transformations. Does energy become what they called heat first before it becomes light? Or do the conversions happen simultaneously? A chemistry teacher in another group suggested that the objects of interest should be the electrons that were moving in the wires. But how were the electrons carrying the energy? In which ways were the electrons different before they got to the filament than after they had traversed it? Surely, some said, the electric field in the connecting wires made the electrons speed up while the collisions slowed them down and increased the temperature of the circuit. But how could one reconcile the (almost) zero potential drop across the connecting wires with the participants’ need to have a non-zero electric field inside them?

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\(^1\) The facilitator would have entertained a description using redistribution of surface charges and an energy flow analysis based on the Poynting vector. In the facilitator’s experience with scores of high school teachers in the U.S., Cyprus, and Qatar, this description is yet to be raised.
This short vignette illustrates that distal energy conservation, encapsulated by the slogan “decrease in chemical energy in the battery equals “heat” plus “light,”” provides a completely different kind of cognitive engagement with the phenomena to be explained than the task of local energy tracking. To be sure, distal energy conservation is an important goal of instruction. But local energy tracking helps develop explanations that involve causal agents, which transfer or transform energy through specific mechanisms, in a specific order, while keeping the number of units of energy in the story fixed. Local energy tracking promotes and is promoted by a metaphor for energy as a quasi-material substance that is located in objects, flows among objects, and accumulates in objects, according to the coordination of the energy story with the underlying causal story.

This metaphor is consistent with all quantities that satisfy a continuity equation. It elevates energy to an ontologically superior position to that of mechanical work and therefore obviates the use of the confusing and misleading pseudo-definition almost universally used in precollege instruction “energy is the ability to do work.” Work (or heat) is but a process through which this or that specific unit of energy crosses boundaries among objects. This “following the local energy flow” assumes that all relevant objects are part of the system—the objects are immobile on the stage, as it were—with energy being the immaterial substance that flows from this to that object, accumulating in some, draining from others, but always present. It is on the stage at the beginning of the show and on the stage at the end of the show.

This approach is philosophically at odds with longstanding calls (and standard university physics practice) to treat energy as an abstract mathematical entity endowed with a set of calculational rules. Energy, we are told, is not to be thought of as anything in particular. The essence of energy lies in its conservation. Energy is a property of systems and therefore the precise specification of the system is of utmost importance. The choice of system specifies what types of energy are allowable (similar to a choice of depreciation method determining what you can and cannot subtract from your taxable income). In this way, objects do not possess energy, as in the substance metaphor, but are associated with specific amount of energy (or, in the cases of potential energy, associated only with the system of mutually interacting objects). Conservation is not a local affair—there is an exact compensation of any change in the amount of energy associated with the guts of the specified system by the net energy transfers through work, heat, etc., associated with the boundaries of the system. You change the system appropriately and what was hitherto work by an external conservative force is now a change in the type of potential energy associated with that conservative force. Now you have work, now you don’t.

One might think that the standard approach (which might be dubbed the no-thing systems approach) has two advantages over the substance metaphor: (a) interaction potential energy is never at risk of being associated with one of the interacting objects given that potential energy is an abstract property only of the system of mutually interacting objects and (b) negative energy presents no problem whatsoever given that there is no inherent preference endowed by the no-thing metaphor to the sign of the number associated with energy. Both issues can be accommodated within the substance metaphor, at a time at which the issues become legitimate questions for the learners. For phenomena in the vicinity of Earth (as are most if not all phenomena that are analyzed in lower grades), we see no problem to an object having gravitational energy, as long as students connect that form of energy with the attractive interaction with Earth. In other words, object X can have gravitational energy only in view of its proximity with Earth. That energy is positive (which nicely sidesteps the second issue) since it can be transformed to energy of motion of that object. When the consideration of the behavior of the same object in the vicinity of different planets arises, or the behavior of mutually gravitating objects of similar masses comes up, then and only then is there a reason to problematize the emplacement of gravitational energy in a single object. Finally, when the need arises again to locate the interaction energy in the field, the field itself may become an object—albeit a different kind of object—that contains energy. Finally, the substance metaphor can accommodate

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1 A reference frame relative to which positions and velocities of objects are to be measured is a common, often unarticulated, prerequisite for both metaphors.

2 Similarly, when the need arises to discuss the effects of the time delay between the emission of radiation by Sun and its arrival by Earth, one can introduce vacuum as yet a different kind of “object” to hold the electromagnetic energy stored in the intervening space.
the meaning of negative energy by learners who recognize that the number of interaction energy units for two mutually attracting objects at a given distance must be fewer than when the objects are at a greater distance. This approach is consistent with the tentative nature of science and the iterative negotiation of meaning that should be the cornerstone of science discourse in the classroom.

**Energy representations that promote energy-as-a-substance metaphor**

In designing Energy Project representations of energy, we have sought to specifically harness the affordances of the energy-as-a-substance metaphor by developing representations that embody that metaphor. Since one of the most basic experiences of substances is that of object permanence, we develop representations in which energy is explicitly shown as being an object or objects. Theories of embodied cognition and cognitive linguistics suggest to us that among all possible objects, a particularly cognitively compelling sense of permanence might be attached to the self, and that use of the human body might have special significance for learning.

**A. Energy Theater: a scientific representation and a learning activity**

We have developed a representation we call “Energy Theater,” in which each participant identifies as a unit of energy. Energy Theater is embodied in two separate senses: it uses the human body to symbolize physical entities and it makes explicit use of a particular experientially grounded metaphor (energy as a quasimaterial substance) (Duit, 1987). We distinguish embodied representations from other instructional activities in which the human body is employed as a physical system (rather than a symbolic system), e.g., for comparing the sensations associated with different forces, pressures, torques, and so on (H. G. Close & Heron, 2011; Pantidos & Patapis, 2005; Pfister & Laws, 1995). Embodied representations are also distinct from activities in which students are active for the sake of physiological stimulation. Though these activities may also enhance learning, we suggest that they do so through different mechanisms than an embodied representation does.

Energy Theater is both a representation (a visual rendering of a scientific phenomenon) and a learning activity (in which participants act jointly to construct scientific ideas). It serves our learning goals by reifying the energy flow among stationary objects on a stage that was alluded to in the previous section.

In Energy Theater, each participant identifies as a unit of energy that has one and only one form at any given time. Each Energy Theater enactment represents the energy transfers and transformations in a specific physical scenario (for example, a refrigerator cooling food or a light bulb starting to light). Objects in the scenario correspond to regions on the floor. As energy moves and changes form in the scenario, participants move to different locations on the floor.

![Figure 1](image)

**Figure 1.** Energy Theater representation of a hand pushing a box across a floor at constant speed.

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1 This section borrows heavily from (Scherr, Close, Close, et al., 2012).

WCPE 2012, Istanbul, Turkey
Figure 1 shows a group of participants engaged in creating an Energy Theater representation of a person pushing a box across a floor at constant speed. In this scenario, chemical energy in the hand transforms into thermal and kinetic energy as the hand moves and warms. Some kinetic energy transfers from the hand to the box, which moves. That kinetic energy is then transformed into thermal energy in the box and transferred to thermal energy in the floor as the box warms from rubbing the floor. Since the speed of the box is constant, kinetic energy transfers into the box from the hand at the same rate that it is reduced in the box via transformation to thermal energy and transfer to the environment.

**B. Energy Cubes**

The Energy Cubes representation is similar to the Energy Theater representation except that instead of chunks of energy being represented by people who move among object areas marked out on the floor, chunks of energy are represented by small cubes that move among object areas marked on a horizontal white-board or sheet of paper (Fig. 2). Different sides of the cubes are marked to signify different forms of energy. As energy transfers among and transforms within objects, users move and flip the cubes around the whiteboard. The Energy Cubes representation is similar to Feynman’s description of energy as a child’s blocks (Feynman, Leighton, & Sands, 1969) but with added features: the location of the block shows the location of the energy and each side of the block shows a different form of the energy.

![Energy Cubes representation of a hand lifting a box vertically.](image)

**Commentary**

The use of these embodied representations and, more generally, the demand for local energy tracking rests on a teacher’s self-confidence in releasing control of the classroom to the creative expression of student ideas, which become visible and for the rigorous defense of which they can be held accountable. In the context of the classroom, where the ivory tower meets the realities of the bazaar, this relinquishing of intellectual control is a novel move for many teachers, can be deeply disconcerting, and can be disorienting on the part of the learners. The analysis of interviews, surveys, and classroom observations of teachers participating in the QSTEP project has indicated that underlying this discomfort is a sense of urgency to cover the required material over which the students will be tested and for which teachers will be accountable. To be sure, data-driven decisions should be the cornerstone of scientific analysis of education. Yet, one wonders about the advisability of an accountability system that cuts our nose to spite our face.

**Acknowledgements:**

This short paper presents ideas and intellectual contributions of many individuals over several years of collaboration among researchers, precollege teachers, and university faculty in thinking about, teaching, and researching this topic. We are especially grateful to Eleanor Close, Hunter Close, Abby Daane, Lezlie
Salvatore DeWater, Leslie Atkins Elliott, Julie Glavic, Benedikt Harrer, Eric Magi, Sam McKagan, Jim Minstrell, Amy Robertson, Adam Schmiere, Lane Seeley, Jim Slavicek, Sherm Williamson, and Michael Wittmann. One of us (SV) acknowledges the gracious hosting of his sabbatical leave by Costas Constantinou and Nikos Papadouris, during which almost daily conversations occurred about the affordances and limitations of a substance metaphor for energy. This work would not have been possible without the conscientious contributions of many hard-working teachers who love their students, in the United States and in Qatar.

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References


Is it Possible to Teach Energy in Preschool Education?

Dimitris Koliopoulos, Department of Educational Sciences and Early Childhood Education, University of Patras

Introduction

In 1982, J. W. Warren made explicit an opinion, which is implicitly shared by certain physicists, suggesting that the energy concept should not be taught in primary and middle school, and, in some cases, not even in a number of secondary schools, because it is a particularly abstract and mathematical concept (Warren 1982). Thirty years later, educational systems and research groups not only don’t share this view but they suggest the introduction of the concept to be at lower levels of education. At the same time, the research community of science education opposed the above suggestion and proceeded to a more systematic study of the teaching and learning of energy (see Driver and Millar, 1985; Koliopoulos & Tiberghien, 1986; Solomon, 1992; Duit & Haeussler, 1994; Lemeignan & Weil-Barais, 1994; Tiberghien & Megalakaki, 1995; Kaper & Goedhart, 2002; Domenech et al, 2007; Solbes, Guisasola & Tarin, 2009; Michelini, Heron & McDermott, 2012).

One of the research questions which has not been adequately addressed is the possibility of developing programs on the energy teaching for the preschool and early primary education. Even though there are several educational projects, the issue that has not been sufficiently addressed so far is if, and in which way, preschool and primary school children understand the energy concept and if they are able to construct descriptive energy models, given the difficulties that arise from its abstract and quantitative nature. In this paper we attempt to substantiate the idea that, under certain conditions, it is possible to teach energy in preschool and early primary education. In this paper we will argue that (a) energy education in preschool and early primary education is not only a product of modern social demands and requirements, but it is also a subject of systematic research from the point of view of science education, (b) there is at least one conceptual model for energy which constitutes an epistemologically valid and psychologically convenient for young children knowledge and (c) preschool and primary school children can possibly construct a ‘precursor’ energy model utilizing a linear causal reasoning during appropriate instructional interventions.

Social demands and research interests related to energy education

Energy is a fundamental scientific concept, which - because of its social importance - is introduced in teaching from the early stages of education. Around the 1970’s, the educational systems of many industrially developed countries showed a special interest in the teaching and learning of energy concepts, largely due to the oil crises. Since that time, this interest remains undiminished. In recent years, international organizations and education systems enhance the discussion about energy education mainly because of the serious environmental problems caused by the energy and resources management on our planet. The European project Intelligent Energy (2009) is a typical example of modern energy education initiative. European Union supports the development of educational projects promoting increased energy efficiency and the use of renewable energy sources. Many of these projects are addressed to preschool and primary school age children.

On the contrary, the research field of science education has dealt with the energy teaching across the different levels of education almost since its formation as an autonomous academic field. The questions raised by the researchers are related to the mental representations that students form regarding the ‘energy’ concept and the possibility of developing innovative teaching interventions. Over the past years, the energy teaching continues to constitute an important research subject not only because the effects of the contemporary energy crisis are getting more prominent and the educational systems are required once again to deal with the situation, but also because the research questions raised in the 80s continue to engage researchers (Millar, 2005; Domenech et al, 2007; Koliopoulos & Constantinou, 2012). One of the research questions which has not been adequately addressed is the possibility of developing programs on the energy teaching available for preschool and primary school. Exploring the conditions under which the teaching of energy in young children is possible is the subject of recent research studies. For example, Colonnese et al. (2012) address the issue of the vertical elaboration of energy in school science, from the elementary to the high school grade level. Even though the idea of energy
as a broad thematic topic or as an organizing framework for the science/physics curriculum has appeared in teaching proposals very early (70’s and 80’s), it is seldom utilized in conventional teaching about energy. In their article, the authors propose a vertically integrated, research-based approach to teaching energy in primary, middle and upper secondary schools. A common theme that runs through all these grade levels is the notion of energy being converted from one form to another. This idea appears in a qualitative manner at the primary grade. Hammer, Goldberg and Fargason (2012) draw on data from the discourse that takes place in a third grade class (conversations between pupils or between teacher and pupils) and they provide evidence of children’s conceptual or epistemological resources that could be productive for developing an understanding of energy. The main thrust of the argument advanced in this study is that this approach allows teachers to ensure a productive teaching and learning context that could help students develop both, conceptual understanding but also an appreciation of the epistemic aspects of science as a domain of human activity.

From the above it seems that the social demands and requirements promote the development of energy education, while research in science education becomes a suitable framework to investigate the epistemological and didactic dimensions of the question raised in the title of this paper.

An appropriate didactical transposition of the energy concept: The energy chain model

What form or forms can the content of energy teaching take in preschool and primary school education? In literature, various explanatory models have already appeared. In this paper, we will argue that it exists at least a qualitative explanatory model for the energy concept which can constitute an appropriate transformation of the scientific knowledge for these educational levels.

The conceptual frame referred to as the energy chain model has been applied both internationally and in Greece mainly at middle school. The conceptual frame has not been expressed uniformly, but nevertheless has some basic characteristics such as:

- It is based on a structure which includes the storage, transfer, transformation, measure, conservation and degradation as basic properties of energy. In reality it constitutes a type of didactic transposition of the scientific knowledge to its school version, which is mainly linked to: (a) the rich tradition of energy synthesis and emergence of the principle of energy conservation that occurred during the 19th century (Kuhn, 1977) and (b) the conceptual frame of macroscopic thermodynamics as it is shaped within the frame of the contemporary science of thermodynamics (Zemansky & Dittman, 1987). In other words, this model is the most epistemologically valid transformation of the scientific knowledge to its school version. The association of the energy chain model with the historical tradition of the birth of the energy concept allows the expression of its qualitative characteristics, which are necessary when teaching young children. In addition, the correlation of the energy chain model with the macroscopic thermodynamics lends the concept a conceptual autonomy and cancels the obligatory in traditional teaching correlation of the concept with the abstract and mathematical concept of work.

- The conceptual frame can assume various qualitative and semi-quantitative representative forms, such as the representations of the function and distribution (Lemeignan & Weil-Barais, 1994), the energy flow diagrams (Falk, Hermann & Schmid, 1983; Viglietta, 1990) or the energy chains which stress the difference between the stored and transferred energy forms (Tiberghien & Megalakaki, 1995; Tiberghien, 1996).

But apart from the epistemological compatibility with the knowledge of reference, the energy chain model presents one more advantage. It is also compatible with the linear causal reasoning, a preferred reasoning from the majority of children and adults when they explain natural phenomena (see unit 4). In unit 5 examples are given about the use of this knowledge in teaching.

Cognitive demands and abilities for young children

In this paper, we will argue that children of preschool and early school age are able to construct after a relevant teaching intervention a precursor energy model utilizing a linear causal reasoning when they attempt to describe natural phenomena, such as the lighting of a lamp or the movement of a small motor using a battery or a photovoltaic cell. It also seems that children of this age are able to discuss issues related to the social use of the concept of energy (e.g., renewable energy).
Over the last decades educational research in the field of preschool and early primary education has accumulated a series of outcomes suggesting that young children construct conceptions and representations on the basis of their interaction with the natural, social and cultural environment in which they develop (Fleer & Robbins, 2003; Gelman & Brenneman, 2004; Eshach & Fried, 2005; Ravanis, 2005). Recent research conducted by the Department of Educational Sciences and Early Childhood Education of the University of Patras (http://energyeducationen.blogspot.com) shows that preschool and early primary children give a physical explanation (and not a teleological explanation which was anticipated) based on a pre – energy mental representation which allows them to describe the macroscopic function of various physical systems (battery - car, compressed spring - car, battery – light bulb, battery - motor) (Koliopoulos et al, 2009; Koliopoulos & Argyropoulou, 2011). To be more specific, it has been observed that many children are capable of describing the previously mentioned systems either as object chains in terms of their function (i.e. the car movement is due to the battery, the lighting of the bulb is due to the battery) or as object chains in terms of distribution (transfer of an action) (i.e. the battery gives electricity to the car and it moves, the battery gives power to the light bulb and it shines) (Lemeignan & Weil-Barais, 1994). These results can be explained by assuming that children activate a linear causal reasoning. According to Halbwachs (1971), this natural causal explanation is the preferred way of representing the physical world to children. In the case of the explanation of the aforementioned phenomena as object chains in terms of distribution, the children seem to construct a cognitive structure which is referred to as ‘transitive thought’ (Piaget & Garcia, 1983; Ravanis, Papamichael & Koulaidis, 2002). This structure contains an intermediate causal factor which links (without always being identified with) the initial cause to the final result of the phenomenon. We can claim that this intermediate causal factor represents an explanation which corresponds to a precursor form of a qualitative energy chain model. Further research is needed in order to investigate the nature and characteristics of this type of reasoning. We believe that by using qualitative methods, such as class observation and individual interviews, the role of the following three parameters should be examined: (a) the selected physical systems, (b) the suggested schematic representation for the construction of the model and (c) the content of activities – problem sets discussed during the teaching intervention.

Two case studies

Teaching activities addressed to 5-6 year old children are presented reinforcing the hypothesis that it is possible and feasible to introduce energy-related themes in science activities addressed to preschool and early primary school children.

(i) Teaching activities with 5 – 6 year old students. This teaching intervention is addressed to preschool children and consists of five sections of teaching activities: (a) Activities aiming to familiarize children with the suggested phenomenological field (batteries, lamps, motors, solar cells), (b) activities aiming that children explain the various phenomena (lighting the lamp, moving the motor), (c) activities aiming that children represent their explanations in a symbolic way, (d) activities aiming that children make proposals in order to find alternative ways to operate the various devices (e.g., lighting the lamp using a solar cell) and (e) activities aiming that children relate/compare the various school situations to every day situations (e.g., relate the solar cell-toy to the domestic solar cell). The teaching programme is being taught in many kindergartens in Western Greece region within the European project ‘Fibonnaci’ (http://www.fibonacci-project.eu/) which aims at a large dissemination of inquiry-based science and mathematics education in Europe. Some preliminary results concerning the cognitive progress of the children during the teaching intervention are the following: (a) It appears that children can easily be familiarized with the suggested phenomenological field, (b) children can explain the suggested phenomena utilizing the reasoning ‘object chains in terms of function or distribution’ activating their linear causal reasoning, (c) children can easily discuss the concept of sustainable energy sources comparing the advantages and disadvantages of using batteries or photovoltaic cells but (d) the majority of the children represent with difficulty their explanations in a symbolic way.

(ii) Teaching activities with 6 – 7 year old students. This teaching intervention is addressed to early primary education children and consists of five teaching units which include activities similar to those described for the pre-school program. This programme was attended by 105 first grade students from a private...
primary school in the city of Athens. In this case, the cognitive results were satisfactory too. In addition, it was observed that the majority of children was able to construct without any assistance a correct energy chain schematic representation (Koliopoulos & Argyropoulou, 2011). The results from the two case studies indicate that the task to teach a qualitative version of the energy chain model to children aged 5–7 years old is not only cognitively possible but also didactically feasible. More research is needed to determine how the children interact with the proposed educational material in order to construct this knowledge.

References


Energy Transformations in Primary School: Outcomes from a Research Based Experimentation of an Educational Proposal

Francesca Leto, Faculty of Science of Formation, University of Perugia, Italy
Marisa Michelini, Physics Education Research Unit - DCFA - Section of Physics and Mathematics - University of Udine, Italy

Abstract

Energy is a topic which appears many times in Italian curricula. The school puts a strong socio-economical attention to protection of the environment and experts often are invited to make speeches on this topic in primary classroom. This type of approaches are those of newspapers and the common language. A vast literature has highlighted those learning difficulties linked to common sense way of looking to energy concepts and its processing (Millar R. 2005, Heron P., Michelini M. and Stefanel A., 2008). Didactic proposals on energy topic of different approaches (Kaper, W. and Goedhart, M. 2002; Hobson A. 2004) offer to the teacher the opportunity to treat this topic revisiting concepts in such a way as to help children overcome the conceptual knots (Driver R. and Warrington L. 1985; Heron et. al. 2008) that the daily context poses. In a research based experimentation the HMS (HMS - Heron et. al. 2008) approach is adopted to build the concepts of energy by means of experimental exploration, and to complete a teaching of energy based on the content offered by text book: energy form, energy production. The experimental class includes twenty three 8-year-old children of a school of Perugia, Italy. HMS educational path has been applied using Inquiry based learning strategy and monitoring learning by means of boarding diary, in(I)-out(O)- and post(P)-tests (IOP tests). Some interesting elements emerge, especially concerning transformation concept, which appears in different key-situations explored.

Introduction

The concept of Energy plays a central role from a social, productive, applicative and cultural point of view. A vast literature has highlighted how scientific learning requires a strict connection between common sense ideas and scientific ones (Michelini M. 2004, 2007; Prindeaux N. 1995, Watts D. M. and Gilbert J. K. 1983, Vicentini, M. and Mayer, M. 2000). The topic of the energy has been extensively discussed in literature and therefore a big deal of accurate surveys focused on the problems of learning are available (Watts D. M. 1983; Brook, A. J. 1986; Nicholls G. and Ogborn, J. 1993; Pfundt H. and Duit R. 1998, Feynman R. P., 1963, McDermott, L. C. 2001, Solomon, J. 1983, Trumper R. 1993, Carr, M. 1988), and several tested teaching proposals, (Falk, G. Herrmann, F., and Schmid, 1983, Nuffield 1966, McDermott, L.C. 1996, Trumper R. 1990, Papadouris N., Constantinou, CP., Theodora Kyratsi, T., 2008), highlighting specific approaches and perspectives. Moreover, there is a wide range of reviews (Millar R., 2005, Costas) underlining the fact that there is no present effective solution to the educational problem, at any levels. This work is based on HMS teaching proposal on Energy which aims at identifying the knowledge of the different “types” of Energy (kinetic energy, potential gravitational and elastic energy, internal and bright energy) starting from all those “forms” closer to the children’s cultural background in order to found the concept of Energy as a state of property of the systems, by strategies of active teaching and particularly of IBL. This report refers to a research carried out by all my findings in a primary school of Perugia (Italy). The research questions of this experimentation are: How does the global idea and the meaning assigned to any common sense expression, as “to conserve”, “to lose”, “to produce” verbs, change after the path? In which ways do students take hold of the specific language of energy? What are the types of conceptual difficulties by the children for the description of activities?

Methods

The experimentation has been carried out in a 4th level class of 23 8-year-old children of middle ability most of which are foreign but of the primary school. This class, for years, has joined an environmental project which included lectures and educational trips with expert’s guidance. The experimentation has been carried out in 6 teaching hours of activity, plus approx. 40 min for each test.
The rationale of the activities:

1) **Food and the nutritional labels:** Two different types of food with different energy content have been chosen: chocolate (with a high energy content) and salad (with a lower energy content): which of the two foods has a greater energy? The nutritional label expresses the energy content of the food in Kcal and Joule, what is the connection?

2) **Kinetic and bright energy:** the children set in motion the wheel of an bicycle: where does energy of our body go?, we repeating the experiment connecting the dynamo. The children notice that a greater strength of “internal human energy “ is needed to make the bike rotate at the same speed as before and to light the dynamo at the same time. What kinds of transformation we observe?

3) **Energy to fall (potential gravitational):** we identify it as energy of a body placed to a certain height relative to the table and it is called: “energy to fall”. The “energy to fall” of water is transformed into kinetic energy and then in rotational kinetics of the turbine paddle.

4) **Formalization of the potential gravitational energy:** balls of different sizes are dropped in a box full of flour from different heights observing the depth of craters. The potential gravitational energy is formalized as weight for height.

5) **Elastic Energy:** a marble is thrown up by a spear-spring at the height the experimenter had taken it to and even more higher. The “energy of the spring” is as greater as much the spring is compressed.

6) **Internal energy of the bodies:** a marble is left tumbling on the floor. The marble at a certain point stops: where has the kinetic energy of the marble gone? We model some Play-Doh and we observe that it changes shape and it heats up. The internal energy of the bodies in connection with their temperature and their structure is here identified.

7) **Elaboration of the internal energy:** Three transparent little balls of the same dimensions are let fall from the same inclined plane: the first one is completely empty, the second one is filled up with flour and the third one is partly filled with smaller beads. We make an estimation on which one will stop first. The results are discussed.

8) **Many energy transformations:** a toy-car is launched in a track with hills and loops and the children describe the energy transformations involved in the trial.

Monitoring of learning in variational terms was done by the same HMS-test (Heron et. al. 2008) of seven open questions has been applied before the experimentation (test-In), immediately after the path (test-Out) after 3 months from the application of the test out (test-Post).

**Data and Results**

The data analysis is articulated in two phases: in the first one data are analyzed by means of standard methodologies of empirical research, identifying the answers-classes. Non-mutually exclusive typical sentences in the answers to the HMS tests are the operative definition of the various categories. In the second phase, a multi-perspective analysis is carried out. For each question of the HMS test, a table and a graphical representation of categories identified with the operative definition of each category by the children’s typical sentences are discussed. The number of answers for each category (CN) and for each sub-category (SN) are distinguished per kind of test (in- out- post). In the discussion data are reported in percentage, being different the numbers of answers per test.

6.1 Q-1: “What do you know about energy?”

The answers categories to the question Q-1, indicated on Table 1, are those identified in literature (Duit, R. 1984; Watts, D. 1983; Nicholls G, et. al. 1993) except C4, “Renewable/Not-R”. 

**WCPE 2012, Istanbul, Turkey**
Table 1

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SENTENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional- C1</strong></td>
<td>used to operate:</td>
</tr>
<tr>
<td>CN: 12-In; 9-Out; 1-Post</td>
<td>- machines</td>
</tr>
<tr>
<td></td>
<td>- household electrical appliances</td>
</tr>
<tr>
<td><strong>Energy properties- C2</strong></td>
<td>- energy can’t be lost</td>
</tr>
<tr>
<td>CN: 4-In; 6-Out; 9-Post</td>
<td>- Energy is transformed</td>
</tr>
<tr>
<td><strong>Forms- C3</strong></td>
<td>- there is wind or solar energy</td>
</tr>
<tr>
<td>CN: 3-Out; 5-Post</td>
<td></td>
</tr>
<tr>
<td><strong>Renewable/not Renewable-C4</strong></td>
<td>Energy is renewable or not renewable</td>
</tr>
<tr>
<td>CN: 8-In, 7-Out e 12-Post</td>
<td></td>
</tr>
<tr>
<td><strong>Value judgments-C5</strong></td>
<td>Energy is very important</td>
</tr>
<tr>
<td>CN: 4-In, 5-Out; 4-Post</td>
<td></td>
</tr>
<tr>
<td><strong>Have energy- C6</strong></td>
<td>oil and petrol/ methane, water, sun, wind</td>
</tr>
<tr>
<td>CN: 6-Post</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 1. Non-mutually exclusive answers to the question Q-1 organized per categories of table 1.](image)

It is interesting to note that in the Test-Out the distribution of the kind of answers is larger. The functional category (C1) is one of the two largest in entry categories that gradually decreases (54%- In; 42%-Out) in favor of identification of energy properties (18%-In; 28%-Out; 39%-Post). The distinction between renewable energies and non-renewable (C4) is present in all tests (36%-In; 33%-Out; 52%-Post). The possess idea (energy as a state property) appears in the test-Post in witch only in three cases is connected to a substance as of a fuel and in all of the other cases is connected to systems and processes treated into the path.
Q-2 “Are there things that produce energy?”

The answers categories to the question Q-2, indicated on Table 2, are known in literature, (Trumper R. 1993; Dawson, T. L. et al. 2008; Solomon, J. 1983).

Table 2

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SENTENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYSTEMS (C1)</td>
<td>CN: 11-In; 13-Out; 19-Post</td>
</tr>
<tr>
<td>a) Living beings SN:</td>
<td>2-In; 5-Out; 1-Post</td>
</tr>
<tr>
<td>b) Technological Devices SN: 4-In; 5-Out; 22-Post</td>
<td>c) the sun</td>
</tr>
<tr>
<td>c) The sun SN:</td>
<td>5-In, Out e Post</td>
</tr>
<tr>
<td>SUBSTANCES (C2)</td>
<td>CN: 9-In; 11-Out; 4-Post</td>
</tr>
<tr>
<td>ENTITY (C3)</td>
<td>CN: 3-In; 1-Out; 3-Post</td>
</tr>
<tr>
<td>PROCESSES (C4)</td>
<td>CN: 10-In; 7-Out; 2-Post</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SYSTEMS (C1) CN: 11-In; 13-Out; 19-Post</th>
<th>a) the body produces energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Living beings SN: 2-In; 5-Out; 1-Post</td>
<td>b) the wind turbines produce energy</td>
</tr>
<tr>
<td>b) Technological Devices SN: 4-In; 5-Out; 22-Post</td>
<td>c) the sun</td>
</tr>
<tr>
<td>c) The sun SN: 5-In, Out e Post</td>
<td>water, air, food produce energy</td>
</tr>
<tr>
<td>SUBSTANCES (C2) CN: 9-In; 11-Out; 4-Post</td>
<td>light, produce energy</td>
</tr>
<tr>
<td>ENTITY (C3) CN: 3-In; 1-Out; 3-Post</td>
<td>wind turns the turbine blades and so produces energy</td>
</tr>
<tr>
<td>PROCESSES (C4) CN: 10-In; 7-Out; 2-Post</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2 Non-mutually exclusive answers to the question Q-2 organized in categories of table 2

The systems category is one of the most numerous and increases in the test-Post (33%-In; 37%-Out; 67%-Post). Between systems children identify energy conversion devices as solar panels; so they think some processes and center of transformation. In literature, it is highlighted that the idea of energy as an entity is diffused (Duit, R. 1984; Watts, D. 1983). In our specific case is scarcely present in all the three tests and decreases slightly in the test out to increase again in the post test (13%-In; 4%-Out; 13%-Post).

Q-3 “Are there things that have/possess energy”?

The answers categories to the question Q-3, indicated on Table 3, are known in literature, (Trumper R. 1993; Dawson, T. L. et al. 2008; Solomon, J. 1983).
The systems category is the main and dominate in the test-Post. In the test-In there is more richness of answers but these are example of local vision in which energy is connected to substances or specific systems (59%-In). In the test-Out appears systems related to the path, e.g. the toy-car, and in the test-Post there are examples of technological devices, e.g. the solar panels. The solar panels are looked as devices and in this answers is associated to a need to know how these devices work, while in the test-In processes are connected to the environmental situations in the test-Out are connected to energy transformation.

**Q-4 Does energy conserve itself? What conserved means?**

The answers categories to the question Q-4, indicated on Table 4, are known in literature, (Duit, R. 1994; Dawson, T.L., and Stein, Z., 2008; Heron P. et. Al. 2009) except: C2) “Re-used”, C4) “Conservation in space” and C6) “Tautological”.

**Table 4**

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SENTENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1) To archive, store</td>
<td>To conserve means to keep an object for a long time</td>
</tr>
<tr>
<td>NC: (14-In, 16-Out, 15-Post)</td>
<td></td>
</tr>
<tr>
<td>C2) Re-used</td>
<td>re-use energy</td>
</tr>
<tr>
<td>NC: (3-In; 6-Out; 3-Post)</td>
<td></td>
</tr>
<tr>
<td>C3) Transfer</td>
<td>it passes from one body to another</td>
</tr>
<tr>
<td>NC: 1-Out</td>
<td></td>
</tr>
<tr>
<td>C4) Conservation in space</td>
<td>it is conserved anywhere</td>
</tr>
<tr>
<td>NC: 1-Post</td>
<td></td>
</tr>
<tr>
<td>C6) Tautological</td>
<td>Conserved means it conserves itself</td>
</tr>
<tr>
<td>NC:3-In; 1-Out</td>
<td></td>
</tr>
<tr>
<td>C9) Own</td>
<td>conserved means to have something</td>
</tr>
<tr>
<td>(1-In; 2-Post)</td>
<td></td>
</tr>
</tbody>
</table>

The children idea of conservation is related to archive, store and own (63%-In; 76%-Out; 65%-Post): this is a tendency diffused among the students of primary school and known in literature. (Dawson, T.L. et al, 2008; Trumper, R., 1993; Pfundt, H. & Duit, R. 1998). There are cases that connect the conservation to the energy loss and to its potential re-use: this idea increases in the test out and then decreases in the post-
test (13%-In; 28%-Out; 13%-Post). Ideas such as “conservation in space” or “transfer” are expressed by single pupils.

**Q5) Energy can be transformed?**

The answers categories to the question Q-5, indicated on Table 5, are known in literature (Gilbert, J. K., et al. 1983; Stead, B., 1980; Brook, A. J., et al. 1988; Carr, M. et. al. 1988) except C6 “Evolution” and C7 “Regeneration”.

![Figure 4. Non-mutually exclusive answers to the question Q-5 organized in categories of table 5.](image)

In the Test-In energy transformation idea is connected to regeneration (21%), evolution (28%) of forms (14%), substances and entities (28%). In the test-Out appear descriptions from physics point of view such as chains of types that are transformed (22%) and transferred (20%). The description of processes are many: children describe mainly those energy transformations observed during activities (40%-Out; 26%-Post), but often in terms of actions (18%). After three months all categories are present except “evolution” and “regeneration”.

**Q-6 Energy can be lost?**

The answers categories to the question Q-6, indicated on Table 6, are known in literature (Goldring, Osborne 1994; Duit, R. 1984) except C1 “Transformation” and C2 “Evolution”.

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Table 6

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SENTENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C1) Transformation</strong></td>
<td>a) it moves from one body to another</td>
</tr>
<tr>
<td>NC: 8-Out; 3-Post</td>
<td>b) when a toy-car takes a route and enters the loop its energy to fall decreases while its energy of motion increases.</td>
</tr>
<tr>
<td>Students see the transformation in terms of:</td>
<td>c) it can’t be lost but it is transformed</td>
</tr>
<tr>
<td>a) transfer SN: 1-Out, 2-Post</td>
<td>d) energy to fall, motion and bright energies are transformed.</td>
</tr>
<tr>
<td>b) transformation chain SN: 3-Out and Post</td>
<td></td>
</tr>
<tr>
<td>c) general affirmation SN: 2-Out</td>
<td></td>
</tr>
<tr>
<td>d) transforming types SN: 2-Out</td>
<td></td>
</tr>
<tr>
<td><strong>C2) Evolution</strong></td>
<td><em>it can be lost:</em></td>
</tr>
<tr>
<td>NC: 8-In; 5-Out; 3-Post</td>
<td>a) the fox runs and wastes energy</td>
</tr>
<tr>
<td>a) food-chain</td>
<td>b) when you make physical activity lose your energy.</td>
</tr>
<tr>
<td>SN: 5-In, 3-Out, 1-Post</td>
<td><em>It can't be lost:</em></td>
</tr>
<tr>
<td>b) livings</td>
<td>a) Tiger eats a deer and takes his energy</td>
</tr>
<tr>
<td>SN: 3-In, 2-Out, 3-Post</td>
<td>b) we reproduce it by eating</td>
</tr>
<tr>
<td><strong>C3 Substances</strong></td>
<td>a) energy can be lost: Oil, methane.</td>
</tr>
<tr>
<td>a) substances that lose energy NC:1-Out</td>
<td>b) oil becomes gas.</td>
</tr>
<tr>
<td>b) energy as substance that we lose</td>
<td></td>
</tr>
<tr>
<td>NC: 1-Post</td>
<td></td>
</tr>
<tr>
<td><strong>C4) Use and Waste</strong></td>
<td>a) Energy can be lost or consumed if we waste it</td>
</tr>
<tr>
<td>NC: 2-In and Out</td>
<td>b) we lose it and it cannot be used anymore.</td>
</tr>
<tr>
<td>a) waste SN 1-In, 2-Post</td>
<td></td>
</tr>
<tr>
<td>b) missed use SN: 1-In</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Non-mutually exclusive answers to the question Q-6 organized in categories of table 6.
In the test-Out and Post the number of cases that say “energy can’t be lost” increases (9%-In; 52%-Out; 30%-Post). Transformation category (C1) includes statements about energy loss/not-loss then cases of transfer, transformation chains, general affirmation too. The transformation idea appears only in test-Out and test-Post and becomes the most widespread. Few are the cases that put the loss of Energy in relation to the substances or use and waste (27%-In; 30%-Post); they are present only in test-In and Post. The association of energy loss to the food chain and to the human livings gradually decreases (72%-In; 38%-Out; 30%-Post)

**Q-7 What types of energy do you know about ?**

**Forms:** NC: 21-In; 14-Out. For example: nuclear, solar, wind energy.

**Types:** NC: 11-In; 14-Out. For example: internal, bright energy

![Figure 6](image)

**Figure 6.** Non-mutually exclusive answers to the question Q-7 organized in categories of table 7.

In order to explore the subtle students’ distinction between forms and types of energy, Q7 were submitted only in the test-In and Out. Figure 6 shows how student’s identification of types changes towards of forms between test-In and test-Out though this involves only 20% of students.

**Concluding remarks**

The analysis of different types of answers (before the experimentation- In; immediately after - Out and after three mouth -Post) at the same test shows children’s conceptual evolution about ideas on energy in general, energy possess and production, transformation, conservation, loss and forms versus types of energy. This concepts were discussed with IBL strategy according to the HMS proposal (Heron et al 2008). We observe that the children’s general idea about energy (RQ1) changes from local and functional idea to identification of energy properties; from statements about substances to systems that produce energy (60% out- 82% post), from livings that possess energy (40%-In) to systems related to the path (Q-3: 50% Out, 20% Post); from substances, entities (28%-In) that are transformed to identification of energy transformation processes (40%-Out; 26%-Post). They say energy can’t be lost (61%-Out; 30%-Post). Children take hold of the specific language of energy in different ways (RQ2): identify energy properties (Q-1: 20%-Out), indicate technical device as example of systems that produce energy thinking of centers of transformation (12%-In; 15%-Out; 78%-Post). In all three tests children used “store” or “archived” as a synonym of energy conservation (66%-In; 62%-Out; 83%-Post); the re-used idea is constant too (14%-In; 25%-Out; 16%-Post). Such visions of energy conservation may be a consequence of the indirect treatment of this concept. Another difficulty shown by students (RQ3) is the tendency of describe processes and actions observed in the experiments. At the end of the path, children know the energy types and they use energy types rather forms, identifying the energy possess by considered systems. This help the children to identify energy transformation.

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PCK Approach for Prospective Primary Teachers on Energy

Marisa Michelini, Research Unit in Physics Education, Department DCFA, University of Udine, Italy
Lorenzo Santi, Research Unit in Physics Education, Department DCFA, University of Udine, Italy
Alberto Stefanel, Research Unit in Physics Education, Department DCFA, University of Udine, Italy

Abstract

Research based formative interventions were proposed to different groups of perspective primary teachers (PPT) in three different academic years (2008-2011) to design a formative module on energy for PPT formation. The module include CK and PCK parts and parts where CK and related PCK were connected. Different studies were developed aim to explore the ideas about energy of PPTs and effective strategies than can modifying them giving at the same time a PCK formation. Data were collected from the tutorial worksheets filled by PPTs, the educational paths planned by each PPT for the portfolio, by the PCK questionnaire. It emerges that PPTs before the formative module need criteria to identify energy as physical entity and they do not distinguish between the scientific use of the concept of energy and those in the everyday life. After the formative module they evidenced improvement in CK as well in PCK related to the concept of energy.

Introduction

Primary Teacher education is a challenge which involve the possibility to transfer to the future generations a scientific culture integrated and not marginal; it involves the possibility to give to the students the fundamental scientific elements in a way that allows the students to manage them in games, in stories, in their curious questions. Cultural, conceptual and professional aspects have to be integrated, according to the

Pedagogical Content Knowledge (PCK) approach (Schulman 1986; Magnuson et al. 1999). Main problems in primary teacher preparation regards a poor competence in Content Knowledge (CK), difficulties for the novice in putting into practice the Pedagogical Knowledge (PK) related to specific CK, generalized difficulties in integrating PK and CK (Shullman 1986; Michelini 2004; Abell 2007).

It emerges that primary school teacher’s education requires a significant integration between the specific subject matter and the pedagogic competences (Patchen, Cox-Peterson 2008; Schwartz 2009). The main needs are conceptual knowledge of subject contents and the awareness of conceptual difficulties of learners and alternative content related teaching strategies and methods (Corni et al 2004; Viennot 1995; Abd-El- Khalick et al 2004), implementing an inquiry base learning (IBL – McDermot et al. 1999; Samarapungavan 2008; Schwartz 2009). Relevant open questions remain: how to test the PCK developed by teachers? How to promote competences related to phenomenological exploration, modeling, building formal thinking? How to construct competences in recognizing student learning paths and processes? (Baxter, Ledermann 1999; Park, Oliver 2008).

Educational proposal and classroom work documentation concerning active learning do not address the problem of whether the teacher is oriented to the teaching action, rather than to the student’s learning path (Michelini 2003; Corni et al 2004; Samarapungavan et al 2008). The context of energy, despite of its central role in the curricula of all countries in vertical perspective, is an open problem not very studied in primary school (Solomon 1985, Kruger, Koumaras 1994, Trumper 1997). Teachers’ role is particularly relevant for the learning processes in primary school. It is therefore necessary to develop studies on the role of research based proposal in building the PCK, on the ways for PPT professional development, in particular to provide PCK effectively usable to design active learning educational paths in this problematic area.

Research based formative interventions were proposed to different groups of prospective primary teachers (PPT) in three different academic years (2008-2011) at the University of Udine to design a formative module on energy for PPT’s education. The module was designed to build CK, approaching the concept of energy.
via the concept of work, to develop the PCK focusing on the analysis of a teaching/learning proposal (HMS) based on experimental exploration and inquiry strategy (Heron et al. 2008, 2009, 2011, Colonnese et al. 2012), an educational lab centered on the conceptual nuclei and knots from literature. The formative module carried out is presented here, discussing the most characterizing parts and summarizing the main results and the implications for teacher formation on the light of previous studies aimed to the following research questions: What ideas about energy evidence PPTs’?

What strategies are effective to develop PPTs PCK on energy? How a research based educational proposal on energy produce identification of nucleus and knots? Which role play a) PCK questionnaires and b) research finding in related professional formation? How to test the PPTs PCK on energy?

The context

The formative intervention module (FIM) on energy was experimented with 98-115-112 PPT’s in three different academic years (2008-11), in the context of two university courses for PPT: a Physics Education course (PE - 3,5 cts) and a Physics Education Lab / Seminar (PEL - 3,5 cts). FIM involved the following parts:

1-CK (5-6 hours - PE) – Critical teaching - Lectures modality - on the ENERGY CONCEPT according to a traditional approach based on mechanical work concept, kinetic energy theorem and conservative forces peculiarity to introduce mechanical energy conservation and the first principle of thermodynamics starting from non-conservative forces. At the end a CK QUESTIONNAIRE was proposed as intermediate evaluation test.

2-CK (2 hours - PEL) - Discussion of the rationale of the main research based proposals on energy in literature.

3-CK (5 hours – PEL). Interactive lecture demonstrations and operative group exploration of an energy path proposal (HMS), experimented in primary school (Heron et al. 2008, 2009, Colonnese et al. 2012).

4-PCK (6 hours - PEL). PCK-lab involving PPT’s during 2008-09 in: individual and group analysis of nuclei and knots on energy concept, activated by pedagogic problem solving (PPS) by means of worksheets and relative homework on CK reconstruction and related PCK analysis. Educational path design.

5- Final PCK-Questionnaire. In the first implementation a pre questionnaire was proposed to the PPTs to individuate the initial ideas on energy, in particular related to expression like conservation, transformation, loss, dispersion, transmission of energy (Heron et al. 2008, 2011).

In 2009-10 and 2010-11 the MIF was implemented as following:

1-CK as described + Individual work on the following two tasks: a) List the concepts (nuclei) you consider important about Energy learning; b) Identify the critical questions (knots), explaining the choices made;

2-CK and 3-CK as described in 3 hours.

4-PCK: Individual revision of conceptual Nuclei and Knots (NK) done for the tasks after 1-CK (30 min)

5-PCK: Little group discussion and re-elaboration of NK done in 4-CK (30 min).

6-PCK: Individual homework to revise NK and plan a curricular intervention on energy, presented by means of a conceptual map and a list of questions related to situations.

7-PCK: Final PCK-Questionnaire.

The PCK Questionnaire

The PCK Questionnaire explore two aspects per item in problematic situations: 1) energy conceptual CK: how PPTs analyze each specific conceptual knot from subject point of view; 2) PPT ways of intervention on pupils conceptual knots: how typical pupils’ answers are discussed by the PPTs (Fig.1).

Critical situations and questions (2) are taken by the researches of a wide literature on this field. A cross
check control of a semi-final version is made by two different researchers. The PCK questionnaire on Energy include 9 items on the following conceptual knots (Millar 2005): energy associated to human/living (Solomon 1983; Watts 1983; Nicholls, Ogborn 1993; Trumper 1993; Dawson-Tunik 2005); energy possesses only by moving objects (Stead 1980, Watts 1983), as product of process, existing only during processes (Nicholls, Ogborn 1993; Watts 1983; Duit 1984); energy as force/power (Trumper 1993, Driver, Warrington 1985); different forms of energy and recognition of the form associated to standing objects (Brook, Wells 1988; Carr, Kirkwood 1998); conservation and transformation of energy (Watts 1983; Solomon 1985; Duit 1984; Trumper 1993; Dawson-Tunik 2004).

| In a group of children, one of them says that A) the energy is not conserved, “because is lost”, another adds B) “is lost because it transforms” third adds C) “energy exists only when it is created, the fourth says D)” the energy exhausted, in fact we need to fill up with petrol the car” |
|**3.1 Discuss each answer. (CK part)** |
|**3.2 What knots show the different sentences and how you can deal with children? (PCK part)** |

**Figure 1.** Item 3 of the PCK questionnaire

The detailed discussion of the findings has been presented elsewhere (Heron et al., 2011): in the next section, the main findings will be just summarized.

**Main Results**

From the initial exploration on the concept of energy (in 2008/9) the 88% of PPTs evidenced the need to formulate criteria (of definitions) able to identify energy as physical entity and in about the full sample (95%) they do not distinguish between the scientific use of the concept of energy and those in the everyday life.

From reflection on PCK questions & PCK Questionnaire the PPT (in 2009/2010 and 2010/11) evidence gain in: CK competences, concerning distinction on energy and force concepts (71%), distinction between types and forms of energy (79%), the concepts of energy transformation (74%) and conservation (81%); PCK competences related to the specific CK (from 60% to 85%) and more attention on energy pupils ideas and related learning knots (87%), operative/explorative approach to energy introduction with pupils (73%), coherent use of everyday language (76-81% as concern energy transformation, conservation, transfer; 40% about energy dispersion, lost). A scientific point of view on energy is reached after Group Work: the group work documents resulting from the re-elaboration of the individual answers are better than the union of the single ones (generalized results emerging from all the 37 groups).

From energy path proposal and lab work, great changes emerged concerning the issue considered by PPTs important for teaching/learning the concepts of energy in primary: from an initial need of an assertive definition of what energy is to an operative introduction of energy via simple experiments (77%); from indistinct lists of forms of energy, to a competent distinction between types and forms of energy (88%); from the idea of transformation of energy in other things to transformation of energy from a type to another types (74%); energy concept based on its conservative and transformative nature (64%).

The analysis of the educational projects, after the PCK questionnaire, shows: an operative approach to energy (84%); a great attention to everyday language about energy (reconstruction of the meaning of expressions like: energy loss, energy transportation, energy conservation, waste of energy...) (stressed explicitly in 30% but emerged in 75% of the projects); operative proposals to overcome typical students learning problems (energy associated to systems vs. energy as a diffuse entity (45%); potential and internal energy and energy associate to body at rest (75%)).

The main limit of the projects is the internal coherence in the sequence of the steps in the paths designed.
Concluding Remarks

To investigate how produce an effective formation of prospective primary teachers on their competencies in teaching/learning the concept of energy, in the perspective of Shulman’s PCK, a training module has been developed.

This module develops separately CK and PCK and integrates them also for what concern each specific knot. A further synthesis is reached through designing educational proposals and specific interventions with students. Data analysis evidences that PPTs before the formative module need criteria to identify energy as physical entity and they do not distinguish between the scientific use of the concept of energy and those in the everyday life. After the formative module they evidenced improvement in CK as well in PCK related to the concept of energy. In particular professional development of teachers has emerged on the following aspects:

A) Reflection on relevant concepts and knots from different perspectives, both for the development of CK and the related PCK; B) Educational path analysis and discussion as a reference both for specific interventions, both as a reference for the construction of consistent paths; group work discussion on concepts and knots important for sharing issues; PCK questionnaires to develop conceptual CK and Integration between CK and PK; in particular attention to pupils reasoning and planning intervention activities aim to follow it; Implementing Microteaching monitoring learning processes.

There emerges also a few indications to change/explore the formative module on energy here discussed: integrating the analysis of the reference path in the discussion/formation on concepts because the change in the views of students is much more evident when the concepts are presented in the context of the proposed teaching, rather than addressed separately and then the recomposed, requiring additional steps to reconstruct the contents.

The PCK questionnaire is useful as assessment of PCK, but must be supplemented by an analysis of planning proposals for what concerns the evaluation of the consistency of teaching approaches proposed by the PPTs.

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Part II
Teaching the Concept of Energy to High School and University Students

Energy Forms Versus Energy Carriers the Karlsruhe Approach to Teaching Energy

Michael Pohlig, Karlsruhe Institute of Technology (KIT) Wilhelm-Hausenstein-Gymnasium Durmersheim Germany

1. Before 1841

Energy was born in 1841. It was a difficult birth and it took 64 years, until it was grown up. That was in 1905. The prenatal period was a long and winding road. There existed many words for what later was called energy: motive power [1], living force [2] [3] and work. Most of these expressions are no more in use. But work has survived. If we use work as a physical quantity we use our language in a strange way. We have to say: Work can be done on a body or an object, but it cannot be contained in a body. Work is no function state. But the later energy is.

2. Energy was born in 1841

The physical quantity energy was invented by J. R. Mayer. In those days energy was an indirectly observed quantity and was and is still today often understood as the ability of a physical system or a body to do work on another physical system. Energy was constructed as a conserved quantity. What does this mean? It means if energy of a body decreases, then there must be somebody whose energy increases, and vice versa, if energy of a body increases, then there must be somebody whose energy decreases. Let’s have a look on a falling body. While falling down the distance between the falling body and the earth decreases, – the energy of the gravitational field decreases – and the body gets always faster – the kinetic energy of the body increases – . It is hard to see that the amount of energy which the gravitational field loses is equal to the amount of the increasing kinetic energy. In this sense

\[ E_{\text{grav}} = E_{\text{kin}} \]

is a balance equation. We can illustrate this relationship by two water containers. Blue water in container A increases in the same way as red water in container B decreases. Energy forms are born. It is interesting that nothing is said about what happens with the energy between gravitational field on the one side and the accelerated body on the other side. In the language of our water containers we must establish that nothing is said about what happens to the water between both containers. This is acting at a distance. And therefore, conversion of energy forms is actually a consequence of acting at a distance. This is the reason why we have problems teaching energy forms and energy conservation.

But energy grew up and became older. Unfortunately this was ignored in physics education.
3. Energy got older – local balance of energy 1908

Max Planck wrote in his book “Das Prinzip der Erhaltung der Energie”\textsuperscript{1}[4]: “Let us consider a specifically delimited volume. The mass contained in it is generally not constant, but the increase of mass within a certain time is equal to the mass which entered the volume from outside during this very time. We will deduce quite a similar proposition for the energy of a material system.”\textsuperscript{2}

Translated into the language of mathematics we get the so called continuity equation for energy.

\[
\frac{\partial \rho E}{\partial t} + \text{div}_E \mathbf{J} = 0 \quad (1)
\]

Equation (1) says if at a given point the density of energy decreases, this point is a source of an energy density flow. The “0” on the right hand side of equation (1) says: There is no other way to increase or decrease the density of energy at a given point than by an energy current into this point or an energy current out of this point. In other words energy obeys a local conservation law: energy can neither be created nor destroyed. Using the language of the water container model, we can say: The amount of water in the container A decreases in the same way as the amount of water in container increases, therefore there is a water current out of container A into the container B. Now we can ask, which way does the water (energy) go from container A (system or body A) to container B (system or body B)? And finally, there is no need that the water in the container A has a different color than in the container B. Water is water, no matter in which container the water is. Or retranslated: energy is energy and there is no reason to distinguish between different energy forms.

4. Energy grew up in 1905

Albert Einstein’s famous equation

\[ E = m \cdot c^2 \]

says, that “mass and energy are therefore essentially alike; they are only different expressions for the same thing” [4]. In his book “The evolution of physics” he writes: “... Is a hot piece of iron actually heavier than a cold one? Now, we must answer ‘yes’ to this question.”\textsuperscript{3} Literally, if energy exists in different forms such as kinetic, potential, electrical, chemical, energy, then mass exists in various forms such as kinetic, potential, electrical, and chemical mass. Nobody will ever distinguish between mass forms. If we take Einstein’s theory of mass and energy seriously, there are no more energy forms.

5. Energy Carrier

But how can we talk about energy while we try to avoid energy forms? There is an important fact. Energy never flows alone.

- When energy flows from a heat boiler to a radiator, energy flows together with hot water (better: entropy). We say: hot water (entropy) carries energy.
- When energy flows from a power plant to a light bulb in our house, energy flows together with electricity (electrical charge). We say: electricity (electrical charge) carries energy.
- When energy flows from a gas tank to a motor, energy flows together with gasoline. We say: gasoline carries energy.
- When energy flows from the sun to the earth, energy flows together with light. We say: light carries energy.

\textsuperscript{1} \textsuperscript{1}“The Principle of conservation of Energy”. [2] page 134
\textsuperscript{2} \textsuperscript{2}In German: „…betrachten wir also ein bestimmt abgegrenztes Raumvolumen, so ist die darin enthaltene Masse im allgemeinen nicht konstant, sondern die Änderung (Zunahme) dieser Masse in einem gewissen Zeitraum ist gleich der in dieser Zeit von außen in das Volumen eingetretenen Masse. Ein ganz ähnlichen Satz leiten wir für die Energie eines materiellen Systems ab.“
\textsuperscript{3} \textsuperscript{3}In German: „Ist ein heißes Stück Eisen denn wirklich schwerer als ein kaltes? Jetzt müssen wir diese Frage mit <ja> beantworten." [5]
energy source - energy receiver - energy carrier

The concept of energy carrier is easy to teach and for pupils it is easy to learn. Since there are no energy forms and since we can describe the way energy flows from A to B, the conservation of energy results in a very natural way.

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A Guided Re-invention Path Towards a More Versatile Concept of Energy Conservation For Secondary School Students

P.S.W.M. Logman, W.H. Kaper, Faculty of Science, University of Amsterdam, The Netherlands
A.L. Ellermeijer, Foundation CMA, Amsterdam, The Netherlands

Abstract

Traditionally the concept of energy conservation is introduced as an undisputable physical law that helps us describe many processes. However the usefulness and the validity of the concept of energy conservation evades many students. We intend to make the concept more useful and less abstract to students. To that end we have them reinvent special cases of energy conservation from practical contextual problems. Thereafter the students are asked to combine those special cases to increase their applicability. By extrapolation of the combination process we hope to lead the students further onwards to the idea that whenever necessary a new term can be added to the conservation law. This implies that the law becomes valid for any situation. If the students realize this they have grasped a very useful and true concept of the energy conservation law. In this paper we describe the final educational design which we developed in three rounds. Furthermore we will discuss the results in terms of students’ conceptual development based on the results in one school.

Introduction

In the existing situation in the Netherlands students’ ideas on energy in secondary education are diagnosed as inflexible in formal examination tasks (Borsboom et al., 2008). In current education, the law of energy conservation is taught as an indisputable fact detached from its scientific origin, which may cause the usefulness and validity of the law not to be immediately apparent to students (Borsboom et al., 2008; De Vos et al., 2002). Freudenthal (1991) states that knowledge and ability, when acquired by one’s own activity, stick better and are more readily available than when imposed by others, and thus recommends a guided reinvention approach.

To motivate students and to make them appreciate the relevance and usefulness of science, innovation committees for the exact sciences in the Netherlands have chosen a context-based approach (Eijkelhof et al., 2006). Choosing such an approach brings along two major issues: lack of transfer from one context to another and a difficulty to develop widely applicable, abstract concepts in contexts (e.g. Parchmann et al., 2006). More research is needed on these two issues and the concept of energy conservation illustrates both. If we are able to show we can create a context-based learning trajectory for energy we may be quite sure we can do the same for less abstract concepts as well.

We follow Gilbert in his choice for context as the social circumstances as the most promising interpretation of contexts (cf. Gilbert, 2006): the context decides which knowledge is useful in certain jobs that students may end up doing later on in their lives. This way the usefulness of the law of energy conservation should become apparent to students. We will give our students instructions to perform tasks that people having such jobs would perform as well.

We adhere to Freudenthal’s idea of guided reinvention because we think it helps students to grasp the abstract concept of energy by reinventing it, using their own thoughts and arguments. Guided reinvention is based on mathematics as a human activity and in that sense is closely related to contexts. Ogborn (2012) however states that students will not discover any of the big ideas themselves: the ideas in physics only seem to become more obvious as we get used to them. We can only make those big ideas more familiar to the students, so they will feel they understand them.

The above leads us to the following research questions:

1. Which learning steps can be taken in a teaching-learning strategy to guide students to reinvent the concept of energy conservation within a context-based approach?

2. To which extent are students capable of taking those steps?

The first question will get a tentative answer in the educational design section. The second will be answered in the results section on testing that design.
Educational design

Using design research in three rounds, we have developed an educational design, implementing guided reinvention together with a context-based approach consisting of three separate learning steps.

We assume that for most students it is not possible to reinvent the general law of energy conservation in one go. During the first learning step we hand the students three assignments in which we hope a reinvention of what we call partial laws of energy conservation (e.g. $\sum m\cdot h = k_1$) is inevitable (Logman et al., 2010, 2011). This should show the applicability of the law to the assignment. An example of an assignment is shown in Figure 1.

![Third assignment set in a technological design context](image)

**Figure 1.** Third assignment set in a technological design context

The students were asked to write an advice report on their solutions like design engineers. We used these reports to assess whether the students succeeded in reinventing the intended laws and whether they thought the laws applied to their solution to the assignment.

In a second learning step we handed the students assignments in which they were asked to come up with experiments that connect two partial laws which would help them to write propositions on whether it is possible to combine the involved partial laws into a more general conservation law. The first assignment they got in this stage of the learning trajectory is shown in Figure 2.

---

10 If one extracts laws from experiments involving only gravitational energy one will not add the gravitational acceleration $g$ into this equation because it has no use. $k_1$ is only a constant when there is little friction and all other forms of energy are constant. It may vary over different experiments.
During this assignment, demonstrations of a connecting experiment prepared by the teacher were shown, from which the combination of the involved partial laws was to be deduced by the students (e.g. combining $\sum m \cdot h = k_1$ with $\sum m \cdot c \cdot T = k_2$ to form $\sum m \cdot h + 426 \sum m \cdot c \cdot T = k_3$). We asked the students to write a report like scientists substantiating their propositions on possible combinations of the partial laws in question. Again we used the reports to assess whether the students succeeded in the appropriate combinations of laws and whether they thought that the combined laws were more widely applicable. The last step involves analyzing the combination process so we wanted the students to reflect on this process and asked them whether it is always possible to find a new term whenever one is needed (Figure 3).

1 The “c” in this equation describing the mixing of various hot and cold substances denotes the specific heat of a substance but not in SI units. Historically c was chosen to be 1 (kcal/kg·K) for water. $k_2$ is only a constant when the experiment is well insulated and all other forms of energy are constant. This coefficient is different for different experiments.

2 The specific heat c is here chosen to be 1 (kcal/kg·K) for water. The factor 426 (m/K) stems from Joule’s experiment establishing the mechanical equivalent of heat. The coefficient $k_3$ is only a constant when the experiment has only friction in places where the temperature is measured. Again all other forms of energy need to be constant and the coefficient $k_3$ may vary over different experiments.
We are aiming at the students reinventing the general law of energy conservation by arriving at the assumption that combining a new term into the law is always possible when needed. This matches Feynman's blocks from his Dennis the Menace story in his introduction to energy conservation: in situations that energy appears to be missing such a student will look for a missing term in the law (Feynman et al., 1963). A positive answer would make the conservation law generally applicable. To find out what our students’ opinions were after this reflection process we again asked them to write a scientific report to substantiate their opinions. An overview of the three planned learning steps and their conceptual goals are shown in Figure 4.

![Figure 4. Intended learning trajectory towards the general law of energy conservation](image)

For the students to be able to take learning step b at least two partial laws need to be reinvented. To be able to take the final learning step c, in our opinion the students need to perform at least two combinations and therefore at least three partial laws need to be reinvented. Bearing this in mind we chose to have the students reinvent in total four partial laws of energy conservation (4x learning step a) and combine them into an ever more general law in three separate steps, adding one term at a time (3x learning step b). During the last of these three combinations the students were to reflect upon the combination process and check whether the steps needed in that process can always be performed (1x learning step c).

We have developed this material in 3 rounds in 7 different schools in the vicinity of Amsterdam. The material replaces the quantitative introduction of energy. The students worked on the material in groups of two or three. In this paper we discuss the results of 13 groups of sixteen-year-olds of the teacher that tried the material most recently. To save time, about half the groups took on assignment two and the other half took on assignment three. Both assignments were discussed afterwards to make sure all the students were informed about them. During the fifth assignment one of the groups split into two to recombine with another group during the last assignment. Learning step c has only been tested during the last two rounds.

**Results**

In this section we present the students’ achievements per learning step (see Figure 4).

In the first learning step the first of three assignments was to design a lifting apparatus to lift a capstone on top of pillars in ancient Greece. While the researchers expected four types of solutions involving either pulleys, gears, reels, or levers our students proved to be very ingenious and surprised us by coming up with solutions like steam engines, scissor lifts, hot air balloons, hydraulics, and pneumatics. Figure 5 shows some examples.

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1 The equation at the bottom right is meant to describe the general law of energy conservation including any terms as yet unknown to the students.
Figure 5. Laboratory-scale experiments by students

The experiments that students came up with during the second assignment of designing a thermostatic water tap showed less variety. There was more variety in how students tried to predict the outcome. These varieties reflected in the laws that students came up with (Figure 6).

Figure 6. Examples of physical laws for mixing hot and cold water

During the lessons most groups of students could be guided to come up with a physical law equivalent to the one desired. However, only about half of them used that law in their advice reports and only about a third of the reports showed the derivation of that law from measured data (see Table 1). After a classroom discussion on the reports the students agreed that the reports containing an appropriate law described a better solution than those without. In the third assignment on a rollercoaster a quadratic relationship was to be extracted (see Figure 4) which posed an extra mathematical challenge to our students (Logman et al., 2012).

Table 1. Overview of the results for the first three assignments

<table>
<thead>
<tr>
<th>Reportcontains</th>
<th>Assignment 1</th>
<th>Assignment 2</th>
<th>Assignment 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate law</td>
<td>6/13 (46%)</td>
<td>6/7 (86%)</td>
<td>2/5 (33%)</td>
<td>14/26 (54%)</td>
</tr>
<tr>
<td>Derivation of law</td>
<td>2/13 (15%)</td>
<td>5/7 (71%)</td>
<td>2/6 (33%)</td>
<td>9/26 (35%)</td>
</tr>
</tbody>
</table>

We interpret these results to distinguish between those students that at this point in the learning process grasped the concept well enough to find it useful to their solution (54%) and those amongst them that positively showed they were capable of reinventing the partial laws themselves (35%).

The next set of assignments asked the students whether it is possible to combine the three reinvented partial conservation laws into one.

This involves combining the laws $\sum m \cdot h = k_1$, $\sum m \cdot c \cdot T = k_2$, and $\sum \frac{1}{2} v^2 + \sum g \cdot h = k_4$ into one law. Given that the laws look similar, students were asked to come up with connecting experiments. For the first combination an experiment involving height and temperature was needed, for the second an experiment involving velocity and either height or temperature. Eleven out of thirteen groups succeeded in describing experiments for the first combination, and all groups succeeded in describing experiments for the second. Apparently the students were able to envision situations in which a combined law would be applicable.

For the first combination the teacher now showed the students a demonstration of Joule’s experiment (Figure 7).
Figure 7. Joule’s experiment

To end up with the right proportionality constant between the two terms in the law of energy conservation we gave the students Joule’s original measurements (Joule, 1850). This led to the following law:

\[-(m_1 \cdot \Delta h_1)/(m_2 \cdot c_2 \cdot \Delta T_2) = 426 \text{ m/K}\]

After some rewriting guided by the teacher and expanding the law to multiple objects this resulted in:

\[\sum m \cdot h + 426 \cdot \sum m \cdot c \cdot T = k_3\]

Using the quadratic relationship from the rollercoaster experiment (see Figure 4) in a similar way the term containing velocity was added:

\[\sum m \cdot g \cdot h + 426 \cdot g \cdot m \cdot c \cdot T + \sum \frac{1}{2} \cdot m \cdot v^2 = k_5\]

About 90% of the students could be guided to find the combined law and use it in their scientific report (see Table 2). However, about three quarter of them did not derive the combined law.

Table 2. Overview of the results for the fourth and fifth assignment

<table>
<thead>
<tr>
<th>Report contains</th>
<th>Assignment 4</th>
<th>Assignment 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate combination</td>
<td>11/13 (85%)</td>
<td>13/14 (83%)</td>
<td>24/27 (89%)</td>
</tr>
<tr>
<td>Derivation of combination</td>
<td>3/13 (23%)</td>
<td>4/14 (29%)</td>
<td>7/27 (26%)</td>
</tr>
</tbody>
</table>

Again we interpret these results to distinguish between those students that at this point in the learning process grasped the concept well enough to find it useful to their solution (89%), and those that positively showed they were capable of repeating the combination of the partial laws themselves (26%). However, during these two assignments the students were guided to such an extent by the teacher that we cannot be sure that they really had these capabilities at this point in the learning process. The last assignment aimed at extrapolating the combination process to the idea that whenever necessary a new term can be added to the conservation law. At this stage the students were asked how far the process of combining can be extended and how many terms can be added to the law. Again students were asked for connecting experiments but now had to pinpoint the new characteristic variable as well. The experiments students came up with again were numerous, showing the possible size of the applicability domain of a combined law. For all of the experiments the students could identify the characteristic variable. However, to do so, in cases involving electricity or muscles the teacher had to ask which quantity in the source decreased, leading the students to fuel, ATP, and wind speed amongst others.

At this point the students received a description and data from a fictitious experiment which connects the electric potential energy \(\frac{1}{2} \cdot C \cdot U^2\) of a capacitor to an already known form of energy (thermal energy). During the combination process the students were asked whether the steps taken can always be performed when necessary. Again the students had to substantiate their findings in a report.

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14 The constant \(c\) was earlier chosen to be 1 (kcal/kg·K) for water. A new constant \(c^*\) can be defined as 426·g·1 = 4180 (J/kg·K): the specific heat of water.

WCPE 2012, Istanbul, Turkey
About three quarter of our students showed in their reports that they knew how to derive the new partial law of energy conservation involving $U$ and $T$ (see Table 3). However, only two groups out of 13 managed to combine this new partial law into the already established law. Only one group compared the predicted combination process steps to the steps taken to form a substantiated opinion on whether the law could be expanded whenever needed. After being given the appropriate combination seven more groups were convinced that the law could be expanded whenever needed even though most of them were not capable themselves of adding the new law to the already established law.

Table 3. Overview of the results for the final assignment

<table>
<thead>
<tr>
<th>Report contains</th>
<th>Assignment 6a: Extracting new law</th>
<th>Assignment 6b: Combining new law</th>
<th>Assignment 6c: Extrapolating combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate law</td>
<td>12/13 (92%)</td>
<td>2/13 (15%)</td>
<td>8/13 (62%)</td>
</tr>
<tr>
<td>Derivation of law</td>
<td>10/13 (77%)</td>
<td>2/13 (15%)</td>
<td>1/13 (8%)</td>
</tr>
</tbody>
</table>

We interpret the results in a similar way as before. The number of students that positively showed that they were capable of reinventing a new partial law of energy conservation themselves has grown from 38% (see Table 1) to 77% at this stage in the learning process. However, adding the new law and extrapolating the combination process on their own remained hard for our sixteen-year-old students (respectively 15% and 8% only). No less than 92% of our students used the new law in their report and 62% grasped the concept of energy conservation well enough to state in their reports that they believed a new term can always be added to the law even though they did not appear capable of combining the new term into the law themselves. During this last assignment there was only guidance in giving the appropriate combination so we can be quite sure about the reported numbers of students.

Discussion and conclusions

The most problematic steps our students encountered on the intended learning trajectory were extracting non-linear (e.g. quadratic) relationships from measured data, combining physical laws, and reflecting on a process. In our approach about three quarter of our students were capable of reinventing a partial law of energy conservation. An even larger part grasped the concept of extracting partial laws of energy conservation well enough to apply it in a new assignment. Guided reinvention combined with a context-based approach nearly solved that part of the problem.

The next step of combining partial laws did remain difficult and only a small portion of our sixteen-year-old students were capable of performing an appropriate combination themselves and recognized its applications. However, asking for such a combination goes beyond the requirements of the Dutch curriculum and probably most other curricula as well.

Ogborn (2012) states that students will not discover any of the big ideas themselves: the ideas in physics only seem to become more obvious as we get used to them. We have to agree and disagree with Ogborn on this. Somewhat more than half our students did become more used to the idea of energy conservation and came to think of it as a useful, valid concept. However, a small percentage of students also proved capable of reinventing one of the big ideas in physics completely. This number is perhaps comparable to the number of students that grasp a true conception of energy conservation in traditional education.

Because in more traditional approaches the usefulness and validity of energy conservation evades many students we are satisfied with the results on extracting partial laws of energy conservation and the way in which the students become more familiar with the general law of energy conservation. However the number of students that are capable of combining partial laws and of reinventing the general law of energy conservation can certainly be improved upon. Having only had two rounds of try-outs that incorporated the final step of reinventing the general law of energy conservation we are convinced that there is room for such improvement within our approach. For example an extra combination could be added to the material and the guidance during the combinations could now be diminished gradually. It is also possible to postpone such combinations to higher classes in which the students are perhaps better equipped to overcome the mentioned problems.
References


Focusing on Changes in Teaching about Energy

Yaron Lehavi, The David Yellin College of Education
Bat-Sheva Eylon, Weizmann Institute, Israel
Amnon Hazan, Weizmann Institute, Israel
Yael Bamberger, Weizmann Institute, Israel
Ayelet Weizman, Weizmann Institute, Israel

Abstract

Teaching the concept of Energy, a fundamental concept in any science education curricula, presents a great challenge. The observed difficulties may be attributed to the apparent vagueness regarding the meaning of energy, energy forms, energy transformation/conversion/transfer and energy conservation. A teaching approach, following Karplus (1981) idea of an operational definition of energy change and the first law of thermodynamics as relating energy change of a system to different mechanisms, was developed in order to address this challenge. We employed the concept of energy change as a unifying, measurable (through Joule-like experiments) and concrete property of different kinds of natural processes. “Energy language” was developed, together with teaching materials (activities, representations, demonstrations and experiments) which were administered to 7th grade students. This approach follows the ideas presented in the position paper that summarized the Girep 2010 workshop: Teaching about energy (Eylon & Lehavi, 2010).

Introduction

Teaching the concept of Energy is fundamental in any science education curricula, but, nevertheless, presents a great challenge (Duit, 1984, Solomon, 1992, Goldring & Osborne, 1994; Kaper & Goedhart, 2002; Papadouris et. al. 2008, Lindsey et.al. 2009, Lindsey et.al. 2012). The literature indicates lack of students’ proper understanding of what energy is and what is the meaning of energy transformation, energy conversion, energy transfer and energy conservation. Students also have difficulties related to the interrelation of work and energy and to the role of a system in this regard (Lindsey et.al. 2009, Lindsey et.al. 2012). In the past, many doubts were raised about the use of ‘forms of energy’ in teaching (Summers, 1983; Mak and Young, 1987; Ellse, 1988).

There is lack of consensus among physics educators as to the proper language for describing energy (Wolter et. al. 2002). In particular, the following aspects related to the teaching of energy are not agreed upon: (A) its definition, (B) energy forms, (C) energy transformations/conversions/transfer and (D) energy conservation.

A study of the definition of energy in the context of science education identified many problems (Galili and Lehavi, 2006). Several approaches to address the challenge posed by the definition of energy have been found:

(a) Providing no definition (Feynman, 1964);
(b) The ability to do work (a mechanical definition);
(c) The cause of events (Millar, 2000);
(d) A definition based on a an operational definition of energy change (Karplus, 1981);
(e) Developing energy transfer and transformation as a theoretical framework that accounts for changes in very different systems (Papadouris et. al, 2008).

The first two approaches seem to provide no, or incomplete, answer to the question what energy is. Approaches (c) – (e) share in common the emphasis they put on processes and changes. In this respect these approaches rest on the first law of thermodynamics. However, approach (c) was criticized for being too ambiguous since there may be alternative physical quantities that can be used for explaining change, e.g. forces (Ogborn, 1986).
The last two approaches (d) & (e) seem to complement each other but differ epistemologically: the former employs an operational definition of energy change, while the latter presents energy as an abstract, trans-phenomenological, concept.

In this paper we describe an attempt to construct an approach for teaching the concept of energy based on the operational definition (d). We employed this approach in constructing a learning unit for 7th grade students.

Table 1. summarizes the challenges related to aspects A – B:¹, ²

<table>
<thead>
<tr>
<th>Difficulties</th>
<th>Related to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Is energy a material entity?</td>
<td>A. The meaning (definition) of energy</td>
</tr>
<tr>
<td>b. How can we distinguish energy scientific content from its everyday</td>
<td></td>
</tr>
<tr>
<td>meaning?</td>
<td></td>
</tr>
<tr>
<td>c. What makes energy one concept and not many?</td>
<td></td>
</tr>
<tr>
<td>d. Is energy an absolute entity?</td>
<td>A. The meaning (definition) of energy</td>
</tr>
<tr>
<td>e. Can we measure energy or is it only an abstract concept?</td>
<td></td>
</tr>
<tr>
<td>f. What does 'energy of an object' mean? (e.g. energy of a chocolate bar)?</td>
<td></td>
</tr>
<tr>
<td>g. How can we indicate the characteristics of energy (e.g. its</td>
<td>B. The meaning of energy forms (types)</td>
</tr>
<tr>
<td>conservation or relativeness) if we don't know what energy is?</td>
<td></td>
</tr>
<tr>
<td>h. Why does energy, unlike other physical concepts, have forms?</td>
<td></td>
</tr>
<tr>
<td>i. What makes these forms a manifestation of the same entity?</td>
<td></td>
</tr>
<tr>
<td>j. How do we know that one form(s) of energy can be transformed into</td>
<td></td>
</tr>
<tr>
<td>other form(s)?</td>
<td></td>
</tr>
<tr>
<td>k. Is energy transformation a consequence of energy conservation?</td>
<td>C. The meaning of energy transformations/ conversions</td>
</tr>
<tr>
<td>l. How do work and heat relate to energy change?</td>
<td>/transfer</td>
</tr>
<tr>
<td>m. If energy is not a material entity, how can it move from one object to</td>
<td></td>
</tr>
<tr>
<td>another?</td>
<td></td>
</tr>
<tr>
<td>n. How do we know that energy is conserved?</td>
<td></td>
</tr>
<tr>
<td>o. Is energy conservation an empirical law of nature?</td>
<td></td>
</tr>
<tr>
<td>p. Can one, in principle, refute the energy conservation law?</td>
<td></td>
</tr>
<tr>
<td>q. Is energy conservation a consequence of energy transformation?</td>
<td></td>
</tr>
<tr>
<td>r. Does energy conservation mean that energy cannot be created or destroyed?</td>
<td>D. The meaning of energy conservation</td>
</tr>
<tr>
<td>s. Does energy conservation means that energy cannot be created or destroyed?</td>
<td></td>
</tr>
<tr>
<td>t. Why does energy conservation hold only for isolated systems?</td>
<td></td>
</tr>
<tr>
<td>u. If energy is conserved, what are energy sources?</td>
<td></td>
</tr>
</tbody>
</table>

¹ In some cases the difficulties from one category are closely related to those belonging to another category.
² Most of these questions were at the focus of the Discussion of Strand on Energy in Low Secondary School, held at Girep 2010, Reims.
Employing energy change – designing principles

The following principles guided the construction of the teaching approach:1

A. Definition: Energy change as a quantification of processes. Although energy itself cannot be determined without ambiguity as it has no absolute zero value, a change in the quantity of energy2 can be measured and thus is of physical importance (Reif, 1967, p. 202; Reif, 1965, p. 129). Energy change of a system which goes from one state to another may be defined as the change in certain properties of the system that can be measured by the warming or cooling of a standard object. In a less formal language one may regard energy change as „the capability to cause warming or cooling“.

The mentioned measurements, following joule’s experiments, can lead to the following definition of ‘energy change’ of a system:

“Energy change of a system undergoing some process of change is the capability of this process to change the temperature of a standard object (the measuring device) attached to the changing system.”

Or in a “softer” formulation: “Energy change of a system undergoing some process of change is the capability of this process to heat or cool.”3

‘Energy change’, thus, stands for a measure by a specified operation (and a device) of the change in a system when it goes from one state to another. The details of the process are not significant - only the difference between the different states. It should be noted that the role of a system is emphasized according to this approach.

B. Interpretation of the first law of thermodynamics: The first law of thermodynamics (FLT) relates energy change of a system to two mechanisms:

\[ \Delta E = W + Q \]

Following Joule’s approach, we interpret the right side of the FLT as the various processes by which a system can change and relate them to the measured change in temperature of the measuring device:

Processes \( \mu \Delta T \) (of a certain object)

If one measures separately the effect of each process on the change of temperature, one can unite all the processes that can cause a change in the temperature of a measuring device under one concept (note that heat and work are not distinguished one from another).

This procedure establishes a list of different processes (change in height, change in speed, a chemical change etc.) that share in common their capability to produce the same effect: changing the temperature of a certain object. We can hence justify the need to call this common result by the same name: a change of energy. We thus employ at this point a limited interpretation, valid only for cases where a change in temperature occurs, of the first law of thermodynamics:

Processes \( \mu \Delta T \) (of a standard object) \( \circ \Delta E \)

The generalization to other processes is left for the next steps of the procedure and will be presented in the following.

C. Parameters characterizing processes: The various processes by which a system can change are characterized by a change in variables such as height, temperature, speed etc. These variables can either

1 These principles are not meant to be presented to students. We believe, though, that teachers should be aware of them.
2 In the literature, energy change is often used as a synonym for energy transformation. Here we use the term solely to describe the change in the quantity of energy.
3 In order to avoid misunderstanding, one should note that the capability of a certain process to cause warming or cooling does not mean that this is the main result of that process. The main argument here is to point to the common feature that can link between the different processes that occur in nature.
increase or decrease, indicating a similar change in the amount of energy corresponding to the process. Thus, one may attribute a label for the change in the amount of energy corresponding to the changing parameter: change in kinetic energy, change in height energy, change in chemical energy etc. Note that these are only labels that indicate on the nature of the process by which the energy either increased or decreased. There are no different forms of energy but only different types of processes by which energy can change.

**D. Simultaneity of changes:** An observation of various processes in nature reveals that they cannot be described by the change in one parameter only. When an apple falls from a tree, for instance, its height and its speed (not to mention the temperature of the apple and the surrounding air) change simultaneously. This observation enables to relate energy changes in simultaneous processes. For example the changes in the amount of energy corresponding to the change in the height of the apple and its speed (the 'height energy' and the 'kinetic energy') happen in parallel. Simultaneous changes can occur solely within a system or, in parallel, in the system and in its surroundings. The simultaneity of changes enables to generalize the concept of energy change and apply it to cases beyond those described by temperature change.

**E. Opposite arrows of change:** A further observation reveals that simultaneous changes always occur in such a way that some of them are described by increase in energy and the others by its decrease. For example, the decrease in the height energy when an apple falls is accompanied by an increase in the kinetic energy.

**F. Simultaneous changes in energy can counterbalance each other:** The above mentioned feature of opposite arrows of changes in nature does not necessarily imply that the corresponding changes in energy are mutually counterbalanced. This remains to be determined experimentally. One has to verify that for simultaneous changes the measured increase in energy corresponding to some changes equal to the measured decrease in energy corresponding to the others. In the case of the falling apple, for example, one has first to conduct an experiment of free fall, measuring the height of the apple before falling and the speed of the apple before landing. Then one should conduct Joule-like experiments and measure separately the temperature change caused by the fall of the apple and that caused by stopping the apple from the same speed in which it hits the ground. If those measurements produce the same result, one may conclude that the energy decrease in the height change is fully counterbalanced by the energy increase the speed change. It should be noted that the measurements of energy change are conducted separately for the falling and the halting processes.

**G. Isolated versus non-isolated systems:** The role of a system, as is apparent from the previous discussion, is of great importance in the described approach. The concept of simultaneous changes can be used to define operationally an isolated system:

> “An isolated system is one that any change within it is not accompanied by simultaneous changes in its surroundings.”

If certain changes in the inspected system are accompanied, systematically, by changes in its surroundings, this system might not be isolated. Note, that since the borders of a system are defined arbitrarily, one may transform a non-isolated system into an isolated one by expanding its borders.

As will be demonstrated bellow, the measurable quantity, 'energy change', can provide the meaning of 'energy forms', 'energy transformations', 'energy transfer' and energy conservation.

**The teaching approach**

We developed a teaching unit for 7th grade students according to the above designing principles, revisiting the meaning of energy change, energy transformations and energy conservation. The unit addresses, through observation, phenomena in which certain systems undergo changes. It was presented to over 150 teachers and was administered in about 40 classes. We elaborate below on this approach.

As stated above, our teaching approach, following an operational definition of energy change, suggests a definition oriented teaching. However, the principles presented earlier, being sophisticated conceptually, philosophically and scientifically, cannot be used by students and are not meant for them. A further elaboration was required in order to render these principles accessible for the teachers and their students.
The following ideas\(^1\) were adopted in constructing the teaching approach. These ideas reflect the above listed principles but in a manner more suitable for middle-high school teaching:

**A*+B*. Heating (or cooling) as a common feature of many processes**: The main educational idea here is to develop the students’ awareness to the fact that many processes in nature can cause heating or cooling: the burn of a candle, the motion of electric charges, the absorption of light, the cooling of a hot tea cup, etc. While most students are familiar with these phenomena, the capability to heat by a change in height, a change in speed or a change in a spring length is much less known. We developed class activities to demonstrate a large variety of “heating phenomena”.

**C*. Forms of energy indicate different processes**: Forms (or types) of energy may confuse students (or even teachers) since they obscure the fact that energy is one concept. However, in spite of the many doubts mentioned above, we did not abandon the notion of forms of energy due to its importance for teachers (Stylianidou and Ogborn, 1999). We, therefore, adopted the interpretation that ‘forms of energy’ do not indicate differences in the meaning of energy itself, but rather are terms used to label the energy change measured in different processes. The students in our teaching unit are asked to identify through observation which parameter (e.g. speed, height, temperature etc.) can be used to describe the difference between the initial and the final states of a particular system. Then we relate the energy change to the difference in this parameter. The unit stresses that we can only measure differences in the amount of energy occurring in different processes.

**D*+E*. New meaning to ‘Energy transformations’ and ‘energy transfer’**: The unit stresses that energy, as a quantitative entity, can either increase or decrease. In simultaneous changes, the changing parameters indicate either a decrease in the energy associated with them or its increase. Our unit encourages the students to conclude, through observation, that the decrease of energy in some processes is always accompanied by the increase of energy in the simultaneous processes. We further encourage them to adopt the following interpretation (Wolter et. al. 2002): ‘Energy transformations’ means that the decreased ‘type of energy’ is ‘transformed’ to the increased ‘type of energy’. Similarly, when one property changes simultaneously for two different systems, this is a reason for saying that energy of a certain ‘type’ is ‘transferred’ from one system to the other.

**F*+G*. An empirical meaning for energy conservation**: We adopt the idea that energy conservation is an empirical law which states that all the measurable energy changes in an isolated system are mutually counterbalanced. We first emphasize the role of a system and then encourage a discussion on whether a certain system is isolated or not. We cannot demonstrate experimentally the validity of the conservation law. Instead, a claim is made regarding the many experiments conducted so far which support the validity of the law. These experiments show that if one considers all the change processes in a system which does not interact with its environment (an isolated system)\(^2\), and attributes to each of them the corresponding energy change, one finds, experimentally, that the energy decrease in various processes is fully counterbalanced by the energy increase in the accompanying processes. Hence, the total energy change in an isolated system adds up to zero.

Principles A*–G*, clearly demonstrate our main goal: to construct a language which emphasizes how the concept of energy is used to describe changes. However, we do not suggest to abandon the traditional language used in teaching the subject of energy, but mainly to provide it with new meanings.

**Examples from the teaching unit**

The first chapter of the unit is called “Energy, Phenomena and Changes”. The chapter first calls attention to changes occurring in various phenomena. It then proceeds with a series of activities demonstrating different ways to cause heating. For example, in order to show that the process of braking can cause heating, the students are asked to stop a rotating bicycle wheel by attaching a thermometer to it (Fig. 1).

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1 Ideas directly related to the design principles as stated above are starred.

2 One may determine whether a certain system is isolated or not by checking if any changes can be detected in its surrounding when the system goes from one state to another.
The students are then urged to look for a common result in the phenomena they examined. The second chapter discusses what is a system and how can we tell that the system changes. The notions of initial and final states are introduced together with the characterizing features of the process of change. The students are challenged to decide how to examine the process:

![Figure 1. A demonstration of the heating capability of a change in speed](image)

**Figure 1.** A demonstration of the heating capability of a change in speed

what are its initial and final states and which of its characterizing features are the most important for the description of the process. For example, the students are asked to describe in this spirit the motion of a bouncing rubber ball. At the next stage the unit calls attention to the fact that changes occur simultaneously. Only then the various changes are related to the concept of energy change. The different changes in the characterizing features described so far are related to changes in energy. The types of energy are related to the changing parameter(s): change in height ® change in height energy, change in speed ® change in kinetic energy, change in a rubber band length ® change in elastic energy etc. The students are asked whether the amount of energy related to each change is either increasing or decreasing. For example, the students are asked what happens to the amount of energy associated with motion and that associated with height when an apple falls.

**Plans for further implementation**

We are now at the process of constructing a unit on the subject of energy based on the approach presented above for 9th grade students. While the 7th grade unit builds the conceptual framework with minimal use of quantification, in 9th grade the unit is much more quantitative and uses formulae. This unit has to build on the conceptual framework developed in the 7th grade and provide the appropriate background for the teaching of energy in secondary school in topics such as mechanics where traditionally the approach of changes is only partially used (e.g. in gravitational potential energy).
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Student Understanding of Work and Energy Concepts at the University Level

P. Heron, Department of Physics, University of Washington
B. Lindsey, Department of Physics, Pennsylvania State University – Greater Allegheny
P. Shaffer, Department of Physics, University of Washington

Abstract

The fundamental role of energy in physics is reflected in the emphasis placed on the concept in science education at all levels. In the United States, guidelines produced by the American Association for the Advancement of Physics and the National Academy of Sciences urge that energy be taught as a central organizing theme beginning in primary school. As a result, students will be exposed to the concept of energy many times before they begin university-level studies. In the US and in many other countries, students who plan to become engineers, chemists, physicists, doctors, etc., take introductory physics courses in which energy is covered during instruction on mechanics, electricity and magnetism, and often thermal physics and quantum mechanics as well. Energy is not necessarily treated consistently in all of these parts of the course. For example, in mechanics it is rare to consider work done BY the system of interest whereas in thermal physics the first law of thermodynamics is often presented in such terms. These inconsistencies may add to students’ difficulty in appreciating the unifying role energy plays in different areas of physics. Despite the importance of energy in the curriculum, there have been relatively few studies that address teaching and learning among post-secondary students. The studies that we will describe contribute to this research base. We are especially interested in student ability to apply the concepts of work and energy to systems that cannot be treated as point particles. In such cases it is crucial to choose a system of interest, recognize which kinds of energy the system may have, identify the interactions of the system with its environment, calculate the work associated with each interaction, and relate the net work done on the system to the change in its total energy. To try to pinpoint sources of student confusion we have designed and administered questions to thousands of university students after relevant instruction by lecture, textbook, and laboratory. The responses reveal several specific conceptual difficulties. In a course on mechanics, students frequently were inconsistent in treating objects as either part of the system of interest or part of the system’s environment; they were unsure as to which displacement to use when calculating work; they tended to attribute potential energy to point particles (and not interacting particles); were confused as to whether net work related to changes in total energy, or just kinetic energy; sometimes treated the sign of work as coordinate-system dependent; and refused to believe that certain groupings of objects could be treated as a system. Some errors are more prevalent in situations involving gravitational potential than elastic potential energy. In a course on electricity and magnetism, students were often confused as to whether work is path-independent. In a course on thermal physics, students sometimes claimed that work could not lead to a change in temperature of a gas. In a course on introductory quantum mechanics, students struggled with the meaning of negative total energy in bound states. Our studies of student conceptual understanding have taken place in the context of a major instructional materials development project conducted by the Physics Education Group at the University of Washington, that has led to the publication of Tutorials. Several tutorials address energy. We present evidence that the tutorials help students overcome some of the conceptual difficulties we identified. Our findings have implications for instruction that aims for a rigorous treatment of energy concepts that is consistent with the first law of thermodynamics. They also have implications for instruction in primary and secondary schools, where students acquire many ideas about energy that may not prepare them for post-secondary studies.
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Part III
Teaching Specific Aspects of the Concept of Energy From Social, and Historical Perspectives

The Beta Decay and the Conservation of Energy: a Historical Case-Study to Overcome Learning Difficulties in the Upper Secondary School

Matteo Leone, Dipartimento di Filosofia e Scienze dell’Educazione, Sezione di Scienze dell’Educazione, Università di Torino matteo.leone@unito.it
Nadia Robotti, Dipartimento di Fisica, Università di Genova – INFN, Sezione di Genova robotti@fisica.unige.it

Abstract
This theoretical paper provides a case-study in the history of nuclear physics that could likely help overcoming a learning difficulty that upper secondary school students have in dealing with conservation of energy topics. As reported in the physics education literature, among the learning difficulties encountered by the students figures indeed limiting the validity of the principle of conservation of energy to mechanical and thermodynamic processes.

The historical case-study here proposed concerns Bohr-Pauli controversy in late 1920s to early 1930s about the continuous beta decay spectra. As it is well known, in order to explain this feature of the beta decay, Bohr suggested a violation of the principle of conservation in radioactive processes. On the contrary, Pauli defended the view that the unobserved portions of energy was carried off by one, or more, very light neutral particles, eventually named neutrinos.

Introduction
Over the years many researchers (e.g. Matthews 1994; Monk & Osborne 1997; Galili 2011) argued for the usefulness of History of science (HoS) in science and physics teaching. Among the main reasons reported for using HoS are its power to promote understanding the nature of science, to provide scientific clarification of the concepts to be taught, and to overcome conceptual difficulties of the students. This theoretical paper provides a case-study in the history of nuclear physics, that is the continuous spectrum of beta decay, that could help especially useful to overcome the learning difficulties that upper secondary school students have in dealing with conservation of energy topics.

The continuous spectrum of beta rays
If a nuclear physicist was asked in the 1920s about the constitution of the nucleus, in all likelihood he would have replied that the nucleus itself is not an elementary particle, but is built up of elementary particles, namely protons and electrons.

To believe that protons were inside the nucleus did not require a great leap of faith, since Ernest Rutherford had discovered in 1919 that protons could be knocked out of light elements by alpha particles bombardment. Electrons also were likely inhabitants of the nuclear world as it was known for several years that they appeared to be ejected by the nuclei during the radioactive beta decay of some heavy elements.

If, on the one hand, by this model of the nucleus, the nuclear origin of the electrons present in the radioactive beta decay was immediately ensured, on the other hand, the presence of the electrons in the nucleus as well as the mechanism of their expulsion in radioactive processes posed a number of serious theoretical problems concerning the confinement of the electron in the nucleus, the electron spin, and the continuous spectrum of beta rays (e.g. Stuewer 1983).
As regards the latest problem, that is the continuous spectrum of beta rays, two possibilities existed in order to explain the heterogeneity of electron energies. According to the first hypothesis, in each disintegration the nucleus emits an electron of a given characteristics energy through a process which is the same for each atom of a nuclide. If this is so, the continuous spectrum of these electrons is due to secondary effects. Under the second hypothesis, the process of electron emission is different for the different atoms of a nuclide, and therefore it might be argued that the continuous spectrum is due to the fact the energy of disintegration is not a constant characteristics of a nuclide.

In 1927, Charles D. Ellis and William A. Wooster, through a well known calorimetric experiment, demonstrated beyond doubt the correctness of the second hypothesis and that therefore the beta electrons are emitted by the nucleus with various energies (Ellis & Wooster 1927; Franklin 2004).

Niels Bohr’s hypothesis

In order to explain the puzzle of the continuous energy spectrum of the electrons in beta decay, as early as July 1, 1929, Niels Bohr sent a note to Wolfgang Pauli discussing the possibility of energy conservation being violated and its possible relevance to the physics mechanisms occurring in the interior of the stars, while admitting that “little basis we possess at present for a theoretical treatment of the problem of b-ray disintegrations” (Bohr 1986, [5]). Pauli’s reply was very negative and in fact Bohr never published his note. Actually, Bohr openly advocated this idea for the first time during a Faraday Lecture to the Chemical Society in London delivered on May 8, 1930. Yet, as remarked in Bohr’s Collected Works, the published text of the lecture, where he wrote that “we have no argument, either empirical or theoretical, for upholding the energy principle in the case of b-ray disintegrations” (Bohr 1932b), was written only in 1932. The first, full, open announcement of Bohr’s idea on this matter occurred in October 1931 during the Rome international conference of nuclear physics, organized by Enrico Fermi among the others. In the section “problems of intra-nuclear electrons” of his paper Atomic stability and conservation laws, sent to Fermi for inclusion in the proceedings of the Rome conference, Bohr discussed the beta decay puzzle after having reported about how quantum mechanics can explain the nuclear disintegrations in which alpha particles are emitted (Bohr 1932a, pp. 129-130).

Just like the a-ray products, all b-ray products have a well-defined rate of decay, but nevertheless for each product the energy of the emitted b-particle varies continuously within wide limits. If energy were conserved in these processes, it would imply that the individual atoms of a given radioactive product were essentially different, and it would be difficult to understand their common rate of decay. If, on the other hand, there is no energy balance, it is possible to explain the law of decay by assuming that all nuclei of the same product are essentially identical.

Wolfgang Pauli’s hypothesis

According to a radically different hypothesis, no less radical than Bohr’s one, the continuous energy spectrum puzzle might be explained through a “ghostly particle” (Reines and Cowan 1956). On December 4, 1930, Pauli put forward just such an hypothesis when he wrote a letter, later to become famous, headed to “Dear radioactive ladies and gentlemen” gathered at a physics meeting in Tübingen, Germany (for an English translation of Pauli’s letter see Brown 1978). Besides explaining that he was unable to attend to the meeting because he was expecting much more from a ball which he wished to attend in Zurich, Pauli wrote in this letter that he had hit upon a “desperate remedy” to save the conservation of energy (and the statistics), namely

the possibility that there could exist in the nuclei electrically neutral particles that I wish to call neutrons, which have spin 1/2 and obey the exclusion principle, and additionally differ from light quanta in that they do not travel with the velocity of light: The mass of the neutron must be of the same order of magnitude as the electron mass and, in any case, not larger than 0.01 proton mass. The continuous b-spectrum would then become understandable by the assumption that in b decay a neutron is emitted together with the electron, in such a way that the sum of the energies of neutron and electron is constant.

Pauli repeated his suggestions about the “neutron” at the 88th meeting of the American Association for the Advancement of Science and associated societies, held in Pasadena, California, from June 15 to 20, 1931. Differently of what Pauli later recalled in a lecture delivered in Zurich in 1957 (Pauli 1964), at the time of Pasadena meeting, Pauli still considered his “neutron” to be a nuclear constituent and kept referring to them as “neutrons” (AAAS 1931).
Two months later, Samuel Goudsmit reported about Pauli’s hypothesis in his paper (written in August 1931) for the Rome conference, where he pointed out that this hypothesis might explain why it seems that the law of conservation of energy is not fulfilled in beta decay (Goudsmit 1932, p. 41). “Pauli’s neutron” did not immediately proved popular, nor was further discussed during the Rome conference. It must be said, however, that the hypothesis of “Pauli’s neutrons” did not solve all the problems posed by the nuclear electrons. In fact, not only it completely left open the subject of electron confinement within the nucleus, but extended this problem to “Pauli’s neutron” itself since even this latter particle would had to be confined within the nucleus.

A few months after the Rome conference (February 1932), a new nuclear constituent was actually discovered at the Cavendish Laboratory in Cambridge through the study of the alpha particles bombardment of beryllium. This new particle, which was understood to be a new uncharged constituent of the nucleus, was about as massive as the proton, and was named by its discoverer, James Chadwick, as “neutron”. Since the mass of Pauli’s neutron was expected to be much smaller than the mass of Chadwick’s neutron, Fermi proposed to call “neutrino” (that is “small neutron”, in Italian language) Pauli’s particle.

As Pauli’s hypothetical neutron, Chadwick’s neutron as well was the output of a strongly held belief in the validation of the principle of conservation of energy. The alternative g-like hypothesis advocated by Frederic Joliot and Irene Curie, as reported by Chadwick (1932), “can only be upheld if the conservation of energy […] be relinquished at some point”.

**Enrico Fermi’s theory of beta decay**

The neutrino hypothesis was first presented for publication by Pauli during the seventh Solvay Conference, held in Brussels on October 22 to 29, 1933. In the discussion section following Werner Heisenberg’s speech on the structure of the nucleus, Pauli negatively commented upon Bohr’s hypothesis that the law of conservation of energy does not hold, and gave some details about the neutrino (Pauli 1934; for an English translation see Brown 1978).

While at the Rome conference the neutrino hypothesis passed largely unnoticed, at the Solvay conference such an hypothesis prompted a brief discussion about the possible experimental methods to detect this elusive hypothetical particle. For example Chadwick, which was present at the conference, noted in this regard that “it is certain that the neutrino, if it does exist, it will be exceedingly difficult to detect”. As matter of fact, however, the neutrino was almost neglected throughout the conference, and it was not seen by those who intervened on the problem of beta decay as one of the possible protagonists of the beta decay. With hindsight, we know that Fermi, who was the only Italian physicist who was invited to attend the Solvay conference, had quite a different approach. In a few weeks, he abandoned indeed his quest for new physical laws on the nuclear scale, that he had been carrying out for some time, and showed how beta decay can be explained within the framework of ordinary quantum mechanics by resorting to the hypothesis of neutrino and to another bold hypothesis, that is the transformation of a particle into another one.

Between December 1933 and January 1934 Fermi published his theory of beta decay (Fermi 1933; 1934a), where he assumed, as Pauli had, that in beta decay both an electron and a neutrino are emitted, and that “the energy liberated during the process would be shared between the two particles, in such a way that the electron energy can take on all values from zero to some maximum”. Under Fermi’s theory, “electrons do not exist as such in the nucleus before beta emission, but [together with neutrinos] acquire existence, so to speak, in the very moment they are emitted” (Fermi 1933; see also Perrin 1933).

While through Pauli’s hypothesis we had a qualitative possibility to explain the experimental facts without abandoning the principle of energy conservation, by Fermi’s theory we had a quantitative tool for explaining phenomena concerning nuclear electrons. In this theory, when a beta decay occurs, a neutron in the nucleus is transformed into a proton, which would “necessarily be connected with the creation of an electron, observed as the beta particle, and of a neutrino [n],” according to the reaction

\[ n \rightarrow p + e^- + \nu \]

By the discovery of artificial radioactivity induced by alpha particles and neutrons, that is the induced positron and electron emission (Guerra et al. 2006; 2012), the natural beta decay was understood to be just one of the possible manifestations of weak interactions.
The success of Fermi’s theory much contributed to the acceptance of neutrino’s hypothesis, as it is shown by the topic of exchange interactions in nuclear physics, that is the interactions that Werner Heisenberg had introduced in order explain the protons plus neutrons nuclear structure, and that one year later were revised by Majorana.

**Concluding remarks**

The confidence in the validity of the principle of energy conservation even within the nucleus domain, had in early 1930s important theoretical and experimental consequences.

In 1930, it led Pauli to propose the existence of a new particle, the neutrino, that, on the one hand allowed to smartly explain the phenomenon of the continuous spectrum of beta rays, but on the other hand worsened the theoretical problems posed by the nuclear electrons. Two years later, the confidence in the principle fostered Chadwick’s experimental discovery of a new nuclear constituent, the neutron. Finally, in 1933 it led Fermi to accept the neutrino and to see it, as well as the beta electrons, as something different of a new nuclear constituent but, rather, as a particle acquiring existence in the very moment it is emitted, because of the transformation of a neutron into a proton.

The domain of validity of the principle of conservation of energy, besides being a crucial issue of the late 1920s – early 1930s nuclear physics, is a major point also in the modern physics education.

As reported in the physics education literature, among the learning difficulties encountered by the students figures indeed limiting the validity of the principle of conservation of energy to mechanical and thermodynamic processes. By structuring an activity where the students are asked to estimate the kinetic energy of an electron emitted during the beta decay of a given chemical element, and to explain the empirical fact that the electrons may assume whatever value within a range of energies, the students are made working on different explanatory hypotheses which can justify the principle of energy conservation. Previous experiences (e.g. Solbes & Tarìn 1998, 2004; Solbes et al 2009), suggest that this path is feasible and successful.

The use of this case-study in a classroom setting would therefore enable us to support or challenge the view (e.g. Monk & Osborne 1997; Galili 2011) that HoS is not only an object of teaching *per se* but is a means of acquiring an element of knowledge.

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“Avoid Entropy Production” – A More Intelligent Motto Than “Save Energy”

F. Herrmann, Karlsruhe Institute of Technology, Germany
f.herrmann@kit.edu

Abstract

One aspect of teaching energy is to instruct our students how energy consumption can be reduced. We shall show that all of the so-called primary energy finally ends up in the production of entropy. In principle, every process with entropy production, i.e. every irreversible process, can be replaced by a reversible process with the same outcome (except entropy production). That means that the theoretical minimum of the energy need of a prosperous society is zero. As a consequence, when teaching about the energy problem of our society, instead of recommending to save energy, we should better recommend to avoid entropy production. Whereas with the motto „Save Energy“ we appeal to restriction, to parsimony or even poverty, the motto „Avoid entropy production“ clearly encourages to use our intelligence, and can thus be more effective.

We shall discuss what is the physical cause of energy losses and how and to what extent they can be avoided. First we have to make clear what is meant by “energy loss”. Let us begin with a simpler question: What is water loss? The house of figure 1 has a leak and the water leaks out. This is water loss. But energy loss is different.

![Figure 1. Water loss](image)

If we had an energy loss of the kind of the water loss in figure 1 it would be easy to remedy. We only had to collect the energy at the leak and bring it to the place where we want it to be. Actually what one calls energy loss is fundamentally different. It is caused by the production of entropy.

Let us remind: Where and when does entropy production take place? Entropy is produced whenever there is a kind of friction: mechanical, electric, thermal or chemical. Or expressed in another way: Whenever an extensive quantity goes down “its own potential” without raising another one. When electric charge flows down an electric potential gradient, without driving a motor, when momentum goes from high to low velocity without driving something to a higher level, when heat goes from high to low temperature without driving a heat engine, when a chemical reaction runs freely, i.e. not in an electrochemical cell.

In each of these cases energy is wasted for the production of entropy instead of doing something useful. But why does entropy production require energy? The only reason is, that the produced entropy is trash and it has to be disposed of like trash. That means that there has to be an entropy current. Now any entropy current \( IS \) is connected with an energy current. The relation between both currents is:

\[
P = T_0 \cdot IS
\]

Here, \( P \) is the energy current, \( IS \) is the entropy current and \( T_0 \) is the temperature of the entropy deposit, i.e. ambient temperature.
Thus, we don’t get rid of the entropy without paying. And we pay with energy. Since we don’t want the entropy back we don’t get the energy back. It is lost. Since entropy has been produced and due to the second law it cannot be destroyed, the process is irreversible.

Everybody knows that energy is in short supply and that it is expensive. That is why we are told that we must save energy. But we now see, that we can formulate this recommendation in another way. Instead of „Save energy“, we can just as well say „Avoid entropy production“.

We claim that the second motto is the better one. It is better for two reasons. The first reason has to do with physics. The motto tell us what we have to do. Avoid friction, electric resistance, free-running chemical reactions and so on. The second reason is psychologic. The motto “Save energy” tells us: restrict yourself, tighten your belt, renounce, resign, in the future you will be poorer than now. The second motto on the contrary appeals to our intelligence. It tells us: be clever, be astute, be smart.

Now, there is an important consequence of all that: All of the so-called useful energy is eventually wasted for entropy production. All of the energy eventually serves to dispose of the entropy that is produced. We all know diagrams like that of Fig. 2. These diagrams suggest something different from what we just said.

At the left hand side the primary energy comes in. It is then transformed, converted or processed in some way, and at the right hand side two flows go out: useful and useless energy (“Energy Services” and “Rejected Energy”).

The “rejected energy” is useless precisely for the reason we have just got to know: It brings entropy away that has been produced in all of the foregoing processes.

But what about the useful energy? The answer is simple: It also ends up in the entropy deposit. Entropy production goes on in all the processes for which the costumer buys the energy. And energy is needed to dispose of this entropy. There are light bulbs, vacuum cleaners, other electric motors that drive something that has friction. And at the end all of the energy, ends up in the great disposal, where it goes together with the produced entropy.

We may ask: But why does the diagram end here? Why doesn’t it show the fate of the energy until the end? Because these diagrams represent only that part of the energy flow and transformation which is interesting for the suppliers. They are not interested in what the customer does with the energy.

We had concluded: Avoid entropy production. But how can entropy production be avoided? How much can we reduce entropy production without endangering our prosperity? We can ask this question to various people: technicians, economists, physicists.

We will here ask it only to the physicist. The answer that physics gives is interesting: Entropy production can completely be avoided. Any irreversible process can be replaced with a reversible one with the same benefit.

This physics point of view can yet be formulated it in another way: The minimum energy consumption of a prosperous society is 0 Watt.

Once again: This is true only as far as physics is concerned. There are technical and economic reasons that prevent us form attaining zero entropy production. But we should not inculpate physics for that. We remind how it works in principle: cars and trains without friction, –physics does not forbid it– electric cables without resistance –physics does not forbid it–, houses that are perfectly thermally insulated –physics does not forbid it–, power plants without a burning fire, but with reversibly working combustion cells –physics does not forbid it.

So there is hope, that the energy problem is not as serious as it might seem.
Figure 2. Energy flow diagram ends where suppliers cash.
How Studying Greenhouse Effect and Global Warming can Help Understanding Energy

Ugo Besson, Anna De Ambrosis and Pasquale Onorato, Department of Physics University of Pavia – Italy

A considerable amount of educational research has been devoted to the teaching and learning of energy concepts and phenomena. Many studies have pointed out students’ common conceptions that can create learning difficulties, and different approaches for teaching energy are designed and experimented. Our experience led us to the conviction that it is necessary to overcome a too de-contextualized and technical approach to physics teaching. In particular, as far as energy issues are concerned, it is necessary to immerse physics contents into the context of scientific culture, by discussing different interpretations which caused historical debates and by considering current issues particularly challenging for students. This means to integrate the Science Technology Society Environment (STSE) approach with the conceptual and procedural dimensions of science learning.

We propose to select specific driving issues which can promote the progressive construction of physics concepts and models while highlighting their scope and value and the connection to students’ cultural context. In this perspective we have developed a teaching learning path, devoted to high school students, around the problem of understanding the greenhouse effect and global warming. We wanted to strictly connect the environmental aspects and the scientific content, and we paid particular attention to the conceptual progression and connections with basic energy concepts: differentiating the concepts of work, heat, internal energy, temperature; considering the role of radiation in thermal phenomena; understanding energy conservation and energy balances in stationary situations of thermal non-equilibrium.

Our approach includes outdoor activities, reflection in the classroom, and experimental work in the laboratory. Based on preliminary research with small groups of students, we defined a sequence of six cognitive steps toward the construction of a coherent explanation of the greenhouse effect. The teaching path was experimented in six high school classes, for a total of 121 students.

We investigated two research questions:

- How can the study of a complex issue such as greenhouse effect and global warming improve understanding of energy concepts?
- What type of materials, experiments, models and schematic representations can favor students’ understanding of this topic?

The results confirm the importance of passing through all the six considered cognitive steps: the greenhouse effect is a complex phenomenon and needs a progressive rapprochement. The analysis of the pre- and post- tests showed clearly an increase in the consideration of the role of radiation in thermal processes, the awareness of energy balance in stationary situations, and a more correct and complex explanation of the greenhouse effect. However many explanations still revealed some imprecision and the idea of “trapping” of sun rays was still used as the easiest explanation of the greenhouse effect. Then a process of refinement of the original teaching sequence was developed leading to the production of new materials for students and a teacher guide, which give more attention and a different way to the introduction of some basic energy concepts. Testing of the refined teaching sequence is now in progress in ten high school classes and new results will be presented at the conference.
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A Simple Picture of Possible Contributions to a Body’s Own Energy

Maria José BM de Almeida, CEMDRX, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Portugal

Energy is a property of bodies. A body – any body – has energy. According to the scientific models, what can we understand by “the energy of a body”? For the energy of a body there are several contributions. Some of them are associated with movements, hence they depend on velocity. They are called kinetic energies. For example, a bottle’s cap sliding on the floor has kinetic energy: its macroscopic movement can either be a translation (all the points of the cap describe equal lines as the cap moves), a rotation or a translation and a rotation (as the cap moves, different points describe different lines). Hence, due to its movement, the cap can have translational and/or rotational kinetic energy (respectively Ekin.trans and Ekin.rot).

But, on the microscopic level, the cap, as any other body, has atoms (eventually grouped in molecules). Although we cannot see atomic movements just by looking at any body, we can detect – for instance with X-rays – that they exist. And we can further notice that these movements are more energetic (it means, have higher velocities) if temperature is higher. Indeed, we can correlate temperature with atomic and molecular movements. This kinetic energy associated with atomic and molecular movements is called internal kinetic energy (Ekin.int).

A body that is not moving can have moving macroscopic parts: for instance, a clock with its pendulum oscillating. The kinetic energy of moving parts adds to the kinetic energy of the body (Ekin.parts).

Up to now we have seen that there is energy associated with any movement, which we called kinetic energy. But there is another fundamental contribution to energy, called potential energy. This is due to some special interactions between bodies. For instance, a body can have gravitational potential energy due to its interaction with the Earth. As a consequence, any body left with no support falls to Earth. However this is not a part of the body’s own energy, because it depends on the interaction with another one.

However, as we have said, a body is a large assembly of atoms. On this assembly atoms interact with each other. Associated with this interaction there is what one calls the body’s internal potential energy (Epot_int). This is a part of any body’s own energy (U).

Hence

\[ U = E_{\text{kin.trans}} + E_{\text{kin.rot}} + E_{\text{kin.parts}} + E_{\text{kin.int}} + E_{\text{pot.int}} \]

If a body is isolated from its surroundings, its own energy \( U \) is constant (it does not change with time). But interactions can change bodies own energies. This can happen either if another body exerts forces on it, producing work, \( W \), or if it is placed in contact with another body at different temperature, exchanging heat, \( Q \), or if electromagnetic radiation (for instance coming from the Sun) impinges on it or leaves it (Rad).

Hence

\[ DU = W + Q + \text{Rad} = D_{E_{\text{kin.trans}}} + D_{E_{\text{kin.rot}}} + D_{E_{\text{kin.parts}}} + D_{E_{\text{kin.int}}} + D_{E_{\text{pot.int}}} \]

Now, if one is lead to understand that “a body” can be any system with defined content and frontiers, this works as a widely general expression for the Principle of Energy Conservation.

This approach is a fairly simple holistic starting strategy to discuss every physics Secondary School level classical situation, where energy conversion and/or transfer are concerned. It has been introduced (1) and discussed during pre-service and in-service teacher education, specifically to deal with 10th level Portuguese Physics Curriculum (2) where Energy is the main theme, applied both to thermodynamics and mechanical systems (translations of rigid bodies).


(2) DES - Programa Física e Química A, 10º ou 11º ano, 2001
http://eec.dgidc.minedu.pt/programas/fisica_e_quimica_a_10_ou_11_anos.pdf
Posters Associated to the Symposium
Teaching and Learning the Concept of Energy from Early Childhood School through University

Reproducing Joule’s Experiment(s) in Teaching the Concept of Energy

Yaron Lehavi, The David Yellin College of Education

“In accordance with the pledge I gave the Royal Society some years ago, I have now the honour to present it with the results of the experiments I have made in order to determine the mechanical equivalent of heat with exactness.” (James Prescott Joule, 1850)

Introduction
In his famous series of experiments, James Prescott Joule claimed to find relations between heat and other phenomena e.g. chemical affinity, electromotive and electro-magnetic forces and even the passage of water through narrow tubes. Joule’s experiments, and especially the mechanical equivalent of heat (MEH) experiment, provided a standard measure of processes belonging to domains in nature considered to be disconnected. They laid the basis for our understanding of the concept of energy change as a measure of such processes. Moreover, the fact that there is no dynamical relation for the Joule MEH experiment renders its importance for justifying the use of the energy language (Arons, 1999).

Surprisingly, however, Joule’s MEH experiment was excluded from the curricula, symbolizing degradation in the status of energy conservation in physics education (Bécu-Robinault and Tiberghien, 1998). That, in spite of the recognized importance of Joule’s experiments for teaching the subject of thermodynamics (Sichau, 2000).

Therefore, due to the great importance of joule’s conclusion with regard to the generality of his standard measure of different phenomena, it is highly desired to reproduce his main experimental results. In this paper we introduce a very simple device by which one can relate a change in height, speed and spring’s length to the process of heating a “standard” body. The temperature rise of this body might be agreed to be the measure of the change in the quantity of energy in the process causing it.1 The device enabled us to arrive experimentally at the known relations between the change in the amount of energy related to the different mechanical processes and the variables that characterize them.

The experimental setup
The heart of our system, the standard body, is a small copper tube (~1 cm in length, 3 mm in diameter), placed within a wooden block. In this tube, we embedded a sensor taken from a regular lab thermometer. Around the tube we warped a string: the upper end of it could be connected to the axis of a bicycle wheel (with added weights), while its lower end could be connected to a weight or to a spring (the pictures bellow show the apparatus with a falling weight).

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1 This is in accordance with the approach presented in position paper of the workshop on Teaching about energy (Eylon & Lehavi, 2010).
Illustration 1. The experimental setup: 1) the thermometer inserted in; 2) the copper tube (enlarged in the right photo; 3) the string and 4) the falling weight.

Experiments and results

Experiment 1: Heating by the process of falling (height change)

We arranged the setup as described in the above picture. We first dropped the same weight from different heights until it reached its final height and then let different weights fall from the same height. In each time we measured the temperature rise in the copper tube from the beginning of the process to its end. The wheel was used to monitor the process and to ensure that the change from the initial state of the weight to its final state will involve only the change in height and not in speed. The results of these experiments are illustrated in the following graphs:

Experiment 2. Heating by the process of spring contraction (elastic change)

In this experiment, we employed the same setup as before but instead of a falling weight we connected to the lower end of the string to a spring which was attached to the floor. We then stretched the spring and released, repeating the process for several different lengths. In each time we measured the temperature rise in the copper tube from the beginning of the process to its ending. The wheel, as before, was used to monitor the process and to ensure that the change from the initial state to the final state will involve only the change in the spring length. The results of this experiment are illustrated in the following graph:
Graph 2. Measurement of energy change (by temperature change) in the process of elastic contraction. \( x \) denotes the extension of the spring.

Experiment 3: Heating by the process of breaking (speed change)

In this experiment, we connected the string’s lower end to a weight (to keep it tense) and the upper end was held free. We began the experiment by spinning the wheel and measuring its speed (by a regular bicycle speedometer). We then hooked the string’s upper end to the wheel’s axis and waited until the motion of the wheel was stopped.\(^1\) We repeated the process for several initial speeds and in each time measured the temperature rise in the copper tube from the beginning of the process to its end. The results of this experiment are illustrated in the following graph:

Graph 3. Measurement of energy change (by temperature change) in the process of speed change. \( V \) denotes the initial speed of the wheel.

Conclusions and Discussion

The first experiment verifies rather well Joule’s results with respect to a falling body, according to which the change in temperature is linearly proportional to both the change in height and to the mass of the falling body:

\(^1\) The halting process was caused by the friction between the string and the copper tube.
1) \[ \Delta T \propto m \cdot \Delta h \]

The last two experiments extended Joule’s results to two more processes: an elastic contraction and a change in speed of a body:

2) \[ \Delta T \propto \Delta (x^2) \]

3) \[ \Delta T \propto \Delta (v^2) \]

respectively.

If one accepts the idea that temperature change of a standard body can define (operationally) the change in the quantity of energy in the above processes, one can attribute the above relations to such changes. In other words, one may claim that relations 1 to 3 describe the change in the quantity of energy in the processes of falling, elastic deformation and speed change respectively.

We therefore highly recommend the integration of the above described experiments into any curricula addressing the subject of energy.

Acknowledgements

I could not carry out the experiments described here without the skills and original thinking of Mr. Yosef Sosnovsky and Mr. Mordechay Moshitzky from the Davidson Institute of Science Education at the Weizmann Institute of Science.

References


Report of the workshop in GIREP Conference in France – Reims 2010
Teaching about Energy. Which Concepts should be Taught at Which Educational Level?

Paula R.L. Heron, Department of Physics, University of Washington, USA,
Marisa Michelini, Physics Education Research Unit (PERU), University of Udine, Italy,
with the cooperation of Bat-Sheva Eylon, Weizmann Institute, Israel,
Yaron Lehavi, The David Yellin College of Education, Israel
Alberto Stefanel, Physics Education Research Unit (PERU), University of Udine, Italy

Participants

More than 30 colleagues participate to the Workshop offering an important contribution to the wide discussion. Here we report the names and the e-mail addresses, thanking the Girep Committee for the decision to recognize a GIREP Thematic Group on Energy Teaching and Learning.

Pavel Antonov <pavelantonovu@gmail.com>, Esther Bagno <esther.bagno@weizmann.ac.il>, Ugo Besson <ugo.besson@unipv.it>, bblondin@cesi.fr, Marina Castells <marina.castells@ub.edu>, Michele D’Anna <danna@liceolocarno.ch>, Maria José de Almeida <ze@fis.uc.pt>, Bat Sheva Eylon <Bat-sheva.Eylon@weizmann.ac.il>, Igal Galili <igal@mvs.huji.ac.il>, Zofia Golab-Meyer <meyer@th.if.uj.edu.pl>, Paula Heron <pheron@phys.washington.edu>, Pedro Jorge <pedroj@lip.pt>, Dimitrios Koliopoulos <dkoliop@upatras.gr>, Yaron Lehavi <yarlehavi@gmail.com>, Olga Lendaltseva <oendalceva@yandex.ru>, Paul Logman <logman@uva.nl>, Mariani Cristina <cristina.mariani@unimore.it>, mbu.danna@gmail.com, Micheline Marisa <marisa.michelin@uniud.it>, marisa.michelin@uniud.it, Ana Rita Mota <anaritalopesmota@gmail.com>, Valerie Munier <valerie.munier@montpellier.iufm.fr>, Nikos Papadouris <npapa@ucy.ac.cy>, Gesche Pospiech <gesche.pospiech@tu-dresden.de>, Joel Rosenberg <jrosenberg@berkeley.edu>, Lorenzo Santi <lorenzo.santi@uniud.it>, sassi elena <sassi@na.infn.it>, Alberto Stefanel <stefanel@libero.it>, Laurence Viennot <laurence.viennot@univ-paris-diderot.fr>

Introduction

The learning and teaching of energy has been a rich field for research among students ranging in age from primary school through university. Many proposals for how to teach the subject have been guided by this research. In a Symposium at GIREP 2008 in Cyprus, several researchers presented findings with implications for teaching energy concepts. One outcome of the Symposium was the conclusion that no clear consensus exists on the structure of a vertically integrated curriculum for teaching energy. Such a curriculum would allow the coherent introduction of aspects of energy at appropriate ages and ensure continuity from year to year as children progress through the educational system. Some countries have devised national standards or guidelines that include recommendations for different aspects of energy at different grade levels. However in many cases these have not been guided by research. GIREP members are in a unique position to be able to make recommendations that are consistent with our knowledge of how students learn and the special conceptual challenges posed by the topic of energy.

The goal of the Workshop was to make progress toward the challenge outlined above, specifically to make progress toward a unified, research-based view of which energy topics should be taught at which educational level.

Before the workshop two contributions were sent by Dimitris Koliopoulos of University of Patras, Greece and Joel Rosenberg of U.C. Berkeley, California, USA, respectively on teaching energy in preschool and primary education and on Energy for Everyone. This contributions become part of the work group activities: the relative abstracts are reported at the end of this report.

Proceedings of The World Conference on Physics Education 2012
Another contribution for the Workshop discussion was offered by Bat-Sheva Eylon and Yaron Lehavi from Israel by means of an artifact for the discussion: What has changed? - Energy as the language of changes. The text of this contribution is reported after the abstract mentioned.

The Workshop activity was introduced by Marisa Michelini with an overview of the approaches to energy in research literature, a brief report on 2008 Energy Workshop held in Girep Conference in Cyprus and a suggestion of problems to be considered for the WS discussion. Alberto Stefanel presented a research literature overview of the learning problems on energy concept. At the end of this report a single paper offers a critical analysis of the approaches and the learning problems in energy teaching/learning and a bibliographic contribution for an overview of research contributions.

Paula Heron discussed the main results of the Workshop emerging from the discussion organized in three big groups, working for about 90 minutes on teaching/learning energy in primary, low secondary and upper secondary school. In the following the report of Group responsible are reported. The position paper produced by the workshop activity is reported as last part of this report.
Discussion of Strand on Energy in Primary School

Marisa Michelini, Physics Education Research Unit (PERU), University of Udine, Italy

The discussion group on teaching/learning of energy in the primary schools held in many a way, differentiated with respect to the competences and the experience possessed, and above all the way of looking at the problem. There were researchers presenting the problems on learning, on curricula, the authors with innovative curricular proposals in terms of new perspectives and the tools and methods used and teacher’s trainers from different Universities and colleges and primary school teachers. The countries represented by the group were a good number of 11, all representatives aimed with a strong commitment for the development of scientific based education. The idea of addressing the Energy concept has been widely shared, starting from the primary school with the perspective of a vertical curriculum in which concepts related to this subject are gradually refined and completed.

In the first place, the conceptual and problems related to learning energy were examined. An extensive discussion was already held about on how to approach the concept of energy itself. Above all, the teachers requested and were looking for a suitable definition which could be adopted for primary school pupils, because later they may make a reference to anchor, with respect to the concepts. Many researchers are on the contrary oriented towards a gradual operative specification of the energy concept by means of an inquiry based learning activity. They proposed a gradually building the concept, in various specific ludic contexts in which it is operative.

The introduction of a way of thinking at the energy at local level way had been widely considered as the correct way to proceed. It was underlined the effectiveness of learning to create a concept in specific situations and to strengthen the significance proposing the re-use in various situations. In this way, one can build both the intension and extension meanings of the concept of energy. Even more, it was shared that the idea of proposing energy as a new language to discuss about the various phenomena (what happens) in comparison with the actions. The discussion was held on how important it is to collect the ideas of pupils for organizing maps and posters in a large group discussion and then to be reorganized periodically with a deeper study. Emphasizing on this activity, how they look at different visions of Energy in: substances (gasoline, food, electrical charge), different entities (light, electricity), systems (sun, windmill), actions (movement) helps them to set forth the problem about the nature of energy. Similarly, the adjective forms of energy helps them to raise the question on how many forms and the types that synthesize and represent different forms of energy. Thus, it follows the need to understand, like, what is the source of energy and in the relative processes to sense and then understand the day to day activities.

Time was devoted to idea comparison on the possible approaches to energy concept in primary. Some of the documents have been examined, like the NSTA on July 12, 2010, and some articles of the overview on research contributions presented (Michelini M and Stefanel A, reported above) have been discussed. Not even a single common proposal was reached for implementation, but three possible approaches were discussed, considering both the positive and negative aspects.

A qualitative approach based on energy chains has the advantage of understanding the energy as property which could be transformed and possessed in different forms in different systems. The awareness that, this is a property of the state of the system, is not that likely to emerge in this context that maintains a vague idea about the nature of energy.

The approach attributing an independent identity of energy and examines the processes in terms of energy flux could be useful to build, the shift representations from a qualitative to a quantitative level.

The traditional approach that requires a path through the contents of force and work, conservative nature of the force, idea of gravitational potential and elastic energy, and the conservation of mechanical energy are among the most widely used in textbooks and also at low levels for the school pupils, and the teachers confirm conceptual confusion that results from both combined, with a lack of motivation to disorientation and inability to handle the concepts introduced.
The approach to the industrial artifacts is motivating, but it reinforces all the ideas of common sense that one would like to overcome.

Also much had been discussed about the possibility of exceeding the qualitative level for the building of formal thought process. Some experimentations (Heron et al 2008) have had demonstrated the feasibility. At this scope, the points to be clarified are, the nature of energy as the property and the state of the system, the identification of the transformation processes in the interactions and the associated idea of the source of the energy. The significant meaning of storage and dispersion of energy are the most common, everyday examples that come first, much before being transformed into complex industrial transformations. In order to discuss the conservation of energy being aware of their physics meaning, we need a system to be used as referent and in which we can identify the change in energy from time to time.

To understand the differences between types and forms seems to be the most important among the other requirements to complete the interpretive framework and to reconstruct the language of common sense with scientific meanings.

Addressing the description of energy from the most common experiences experienced is the most important suggestion for the curriculum in primary school and then in the first phase, the three processes: the energy of the food and from the food, the energy of motion and energy from the movement and then the energy from the warm bodies.

The richness of the problems faced and then the need to overcome those questions by means of a interaction and experience comparison led to a suggestion upon the request of a GIREP group on energy.
Discussion of Strand on Energy in Lower Secondary School

Bat-Sheva Eylon, Weizmann Institute, Israel,
Yaron Lehavi, The David Yellin College of Education, Israel

The group reacted to aspects related to energy standards presented a recent standards document sent out for comments by NSTA (see appendix).

Members from different countries portrayed a similar picture concerning the prior knowledge on energy with which students arrive to secondary school. In their previous studies students learn that there are different “types” or “forms” of energy; that energy can be “transformed” from one form to another and that energy can be “transferred” or “move” from one body to another. There is no doubt that this is a unique routine, un-paralleled with regard to other scientific concepts. Some members of the group claimed that the traditional ways of teaching about “types” or “forms” of energy in ages 10-14 stand in the way of developing meaningful understanding of the topic since students relate to energy types and transformations as “game of names”.

Indeed research findings suggest that students have difficulties to comprehend the meaning of the concept of energy and the goal of providing a satisfactory functional conceptual understanding of energy is yet to be achieved (Duit, 1984; Goldring & Osborne, 1994; Solomon, 1992). It was suggested that a possible reason for this might be the lack of consensus within the physics education community as to the proper answer to the question what is energy (Papadouris et. al, 2008), whether there is a need to present a definition of energy to students and how.

Few approaches to address the question what is energy were mentioned in the discussion: (a) Providing no answer (in Richard Feynman words: “It is important to realize that in physics today, we have no knowledge what energy is...”); (b) The ability to do work (a mechanical definition); (c) The cause of events (Millar, 2000; (d) A definition based on a an operational definition of energy change (Karplus, 1981); (e) Developing energy transfer and transformation as a theoretical framework that accounts for changes in very different systems (Papadouris et. al, 2008). Members of the strand discussed pros and cons of the various approaches (cf the appended position paper about “Energy as the language of changes”).

The group discussed few difficulties to be addressed in teaching the concept of energy. The following table expands and organizes the discussed difficulties.

The group did not reach an agreement with regard to the question whether to define energy and what might be a proper approach for defining energy but stressed the need to continue the struggle to arrive at such an agreement.
<table>
<thead>
<tr>
<th>Difficulties related to the definition (meaning) of energy</th>
<th>Difficulties related to the conservation of energy</th>
<th>PCK related questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. How can we distinguish its scientific content from its everyday meaning?</td>
<td>a. Does it mean that energy cannot be created or destroyed? Why, then, do we have to stress that the law holds only in closed systems?</td>
<td>a. What should be taught in each age?</td>
</tr>
<tr>
<td>b. How can we convince that it is one concept and not many?</td>
<td>b. How do we know that energy is conserved? Is it a consequence of the transformable nature of energy forms?</td>
<td>b. What cultural perspective should be considered?</td>
</tr>
<tr>
<td>c. Why does it have forms (types)? How can we convince that these types are manifestation of the same entity and do not have different nature?</td>
<td>c. Is it an empirically discovered law of nature or is it imposed on it by us?</td>
<td>c. Should we avoid a definition of energy? Until what age?</td>
</tr>
<tr>
<td>d. How can we tell whether energy is conserved if we don’t know what it is?</td>
<td>d. Can one, in principle, refute the law?</td>
<td>d. What kinds of representations should we adopt?</td>
</tr>
<tr>
<td>e. How do we know that one form(s) of energy can be transformed into other form(s)? Is it a consequence of the law of energy conservation?</td>
<td>e. If energy is conserved, what are energy sources?</td>
<td>e. How should we introduce the meaning of energy?</td>
</tr>
<tr>
<td>f. How should we address the fact that energy has no absolute value?</td>
<td>f.</td>
<td>f. What should be defined for students and what for teachers?</td>
</tr>
<tr>
<td>g. Can we measure energy or is it only an abstract concept?</td>
<td>g.</td>
<td>g. How should we avoid misconceptions related to energy?</td>
</tr>
<tr>
<td>h. What is the meaning of the energy of a body (e.g. a chocolate bar?)</td>
<td>h.</td>
<td></td>
</tr>
<tr>
<td>i. How should we present heat and work?</td>
<td>i.</td>
<td></td>
</tr>
<tr>
<td>j. If energy is not a material entity, how can it move from one object to another?</td>
<td>j.</td>
<td></td>
</tr>
</tbody>
</table>

References


WCPE 2012, Istanbul, Turkey


**Appendix:**

From Public Comment Draft released by NSTA on July 12, 2010

Goals K-12 NSTA

1. Knowing, using, and interpreting scientific explanations of the natural world
2. Generating and evaluating scientific evidence and explanations
3. Understanding the nature and development of scientific knowledge;
4. Participating productively in scientific practices and discourse.

Goals in Physical Science (PS2)

Forces due to fundamental interactions underlie all matter, structures and transformations; balance or imbalance of forces determines stability and change within all systems. (Interactions, Stability, and Change)

*What happens when matter interacts or changes and how do we characterize, explain, and predict what will happen immediately and over time?*

Goals in Physical Science (PS3)

**PS3.A** What is energy? (Descriptions of Energy)

**PS3.B** If energy is conserved, how can we use it? How do food and fuel give us energy? (Energy for life and practical use: The special role of food and fuel)

**PS3.C** Forces and energy transfer are both involved in changes of motion, how are they related? (Relationship Between Energy and Forces)
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Discussion of Strand on Energy in Upper Secondary School

Alberto Stefanel, Physics Education Research Unit (PERU), University of Udine, Italy

During the group discussion emerged the conviction that we need introduce energy as quantity that can give a vision of the world alternative to the vision based on concept force.

The focus of the discussion was the main points to be included in a proposal for Upper Secondary School about energy. Here we resume briefly these points.

Energy is an abstract quantity associated to systems. The identification of the system is crucial speaking about energy, involving other crucial points: insulated/non-insulated system and association to systems of the potential energy; internal energy and change of energy through making work and heating (the processes to change the energy of a system).

Hint: energy is only defined up to an additive constant. What are defined are the variation of energy of a system. For this reason the focus must be on variation of energy and not simply to energy.

Energy is an extensive quantities. For this reason Energy can be think as a material things flowing from a body to another. But heating is the process involving the flux of energy in this case. A proposal on energy must be face energy from this point of view and students must recognize what involve on the conceptual point of view.

Energy is a state quantity, useful to describe state and processes and to develop a vision of the world alternative to the vision based, for instance, on force concept. A problem of research is: how introduce energy as unifying concept, not only in physics but also in all the other science curricula.

An approach to energy in Upper Secondary School must be quantitative and not only qualitative. About the definition of what energy is, for the majority of attendants it is impossible to define completely and exactly what energy is in Upper Secondary School. However, we can (only for someone) open a windows on energy, providing partial, modifiable and improvable definition of energy. For instance research problems are: how approaching energy in upper secondary school starting from a very partial, common in lower secondary school (and incorrect) definition as: “energy is the capacity to do work”; how introduce energy taking into account the way in which energy is treated in other scientific disciplines courses?

Related to the previous point is: Energy as topic outside of the physics context. We need to propose a view on energy integrated and coherent in all the different scientific contexts.

The participants show consensus about approaches starting from kinetic energy. A phenomenological operative modality, following the Feynman style, was suggested as a practicable way to face energy in upper secondary school. Some critical positions was expressed about a purely phenomenological approach in Upper Secondary School (a mission impossible).

Even proposal as J Ogborn one can constitute a referent, there was consensus about this point: we need a very strong research based proposal about teaching/learning energy in upper secondary school, in which energy is characterized recognizing the peculiar meanings of the concepts of conservation, transformation, transfer when applied to it. For instance, energy appears in different types transforming one in other type, remaining at the same time constant in an insulated system and in general being conserved in the universe; momentum or angular momentum are conserved in insulated system in form and not only quantitatively. Moreover, energy is always involved in the processes with other quantities (momentum, electric current..), so students need to identify energy when they analyze a specific process, recognize how energy is involved in this process, distinguish the role of energy and the role of the other quantity. This point is related from one side to the question of energy carrier and from another side to the need of a deep critical analysis of the concept of transfer of energy, that involve or matter movement or wave movement.

Another largely shared point was the inclusion in an approach to energy the treatment of degradation and dissipation of energy. Almost two motivations supported this point: the knot of dissipation of energy...
is involved in everyday life processes and it is relevant about socio-economic issues; an energetic analysis of a process cannot give use instruments to establish the direction of evolution of the process, because we need of another quantity. If energy degradation must be included in the energy chapter on a strictly subject matter point of view remains an open question.

Last point treated was: Energy conservation is related to the space-time homogeneity (in particular when the H of a system is independent on time, energy is conserved). This aspect concern a very deep structure of space-time. Must be included in a reconstruction of the subject. Is possible to treat this point in a proposal for uppers secondary school?

Position paper: Energy as the language of changes

Research findings suggest that the goal of providing a satisfactory functional conceptual understanding of energy is yet to be achieved (Duit, 1984; Goldring & Osborne, 1994; Solomon, 1992). A possible reason for this might be the lack of consensus within physics education as to the proper answer to the question what is energy, considered to be of fundamental importance (Papadouris et. al, 2008).

The following are few approaches to address the question: (a) Providing no answer (in Richard Feynman words: “It is important to realize that in physics today, we have no knowledge what energy is...”); (b) The ability to do work (a mechanical definition); (c) The cause of events (Millar, 2000); (d) A definition based on a an operational definition of energy change (Karplus, 1981); (e) Developing energy transfer and transformation as a theoretical framework that accounts for changes in very different systems (Papadouris et. al, 2008).

The first two approaches seem to provide no, or incomplete, answer to the question what is energy. Approach (c) may limit the necessity to use energy at all since differences in physical quantities may suggest alternative explanations for changes to happen (Ogborn, 1986).

The last two approaches (d) & (e) require some elaboration. They seem to complement each other but differ epistemologically: the former employs an operational definition of energy change, which can be attributed to Joule’s experiments (Robert Karplus suggested melting a standard ice cube), while the latter presents energy as an abstract, transphenomenological, concept. Approach (d) emphasizes the fact that only differences in energy are of physical significance and can be measured (Reif, 1967, p. 202; Reif, 1965, p. 129). The term “energy change” is thus used to describe qualitatively and quantitatively a change in a system when it goes from one state to another. The details of the process are not significant - only the difference between the different states.

It was suggested that the above mentioned approaches (d) and (e) might address these difficulties. According to these approaches the concept of energy is used in describing various processes of change occurring in nature: a falling apple, a burning candle, light absorbed in a solar panel, the cooling of a hot cup of tea etc. These processes are clearly very different from each other in terms of the factors and the systems they involve and it is not apparent why they can be described by one concept. Approach (d) suggests that the common denominator for many processes may rest on how one can evaluate process of change by measurement. In the past, until the famous experiment of Joule, it was not obvious that there is a connection between such different processes. While some seemed to share the ability to heat a body, others, like a body falling from a certain height or a change in a body’s speed, seemed to posseses no such quality. Joule showed that the process of falling can lead to warming (of water) and thus motivated scientists to describe all the processes that can cause a change in temperature with one concept: "energy

1 This paper, written by Bat-Sheva Eylon and Yaron Lehavi, present the main ideas developed during the Workshop on Teaching about energy. Which concepts should be taught at which educational level? organized by Paula R.L. Heron and Marisa Michelini, with the cooperation of Bat-Sheva Eylon, Yaron Lehavi and Alberto Stefanel in 2010 Reims Girep Congress.
change". The term energy change appeared to be very successful in describing many processes, some of which, such as nuclear processes, absorption of infrared or ultra violet radiation, were unknown in Joule's times.1

Energy change of a system may thus be defined as the measure of its change, during some processes, determined by the warming (or cooling) of a standard object. In a more free language we may define energy change as follows: "energy change is the ability to cause warming (or cooling)." Such a definition, as one may see from many examples, often addresses the daily experience of students regarding the various processes that can cause temperature change. The definition of energy follows the definition of energy change through observation: one should observe which parameter (e.g. speed, height, temperature etc.) can be used to describe the difference between the initial and the final states of a particular system and relate the energy change to the difference in this parameter. Such a relation, as found experimentally, is not necessarily linear.

The one concept, determined without any ambiguity, "energy change", can be used to clarify the meaning of such terms as "types" or "forms" of energy, energy "transformation", energy "conversion" or "transfer" of energy. The use of energy change in describing different types of processes might be the reason for generating the special jargon. Thus, it is due to the convenience of speech that we use different names for energy: kinetic, potential, chemical, nuclear etc. They remind one the process that they describe and its nature.

Despite the different names, one may easily trace back the common denominator for all the above mentioned processes: they could all be used by Joule to heat water. Importantly, not all the details of the various processes are accessible to our senses. For example, when we light a match we can clearly see how it changes but not the changes in the air around it; when a warm object comes into contact with a cold one only the change in each object's temperature is discernible but not the process of change occurring at their microscopic level.

Energy conversion, or transformation, is also used for convenience. If one examines carefully processes in nature, one may observe a very interesting phenomenon: any change is always accompanied by other change(s) and, moreover, the directions of the changes are opposite: if the value of the parameters of one (or some) process of change increase (or decrease) the tendency of others will be the opposite. For example, when an object falls, its decrease in height is always accompanied, simultaneously, by an increase in speed; When a candle burns, the wax (and the free oxygen around the candle) is consumed and, at the same time, the candle (and the air around it) is heated; When light is absorbed (and vanishes) at the solar heater panel the water are, simultaneously, heated.

This phenomenon of "simultaneous variations" can be described simply by specifying the fact that when the measure of one (or more) energy "type" decreases, that of other (or others) increases. However, this non-causal manner of speech did not take roots and, instead, the use of "energy conversion" took over, meaning that the type of energy decreased is "converted" to the type of energy increased. One should be aware of the possible deficiency of such a routine of speech: it may imply that the nature of energy is changed.

Conservation of energy may also be deduced from the measured concept of energy change. Many experiments conducted so far show that if one considers all the changes in a system which does not interact with its environment (a closed system) and measures the energy changes attributed to each of them independently one finds, experimentally, that the energy decrease in various processes is fully counterbalanced by the energy increase in the accompanying processes. Hence, the total energy change in a closed system adds up to zero.

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1 In order to avoid misunderstanding, one should note that the fact that a certain process can lead to warming, does not compel the latter to be the main result of this process (as, for example, when electrical charges flow through a bulb's filament). The main thing is to point at the common feature that can link between the different processes that occur in nature.
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Report of the Workshop in GIREP-EPEC Conference in Finland on Teaching and Learning the Energy Concept and Teacher Formation in Primary School

Federico Corni, University of Modena and Reggio Emilia, Italy
Marisa Michelini and Lorenzo Santi, University of Udine, Italy

Abstract

The ways students, ranging in age from primary school through university, learn about energy and how this concept can be taught, have been productive subjects of physics education research (Duit, 1984; Goldring & Osborne, 1994; Solomon, 1992). Many proposals about how to teach the subject have been influenced by this research. Several researchers presented findings at a Symposium at GIREP 2008 in Cyprus that have implications for teaching energy concept. One of the conclusions reached at the Symposium was that no clear consensus exists regarding the structure of a vertically integrated curriculum for teaching energy. At the GIREP 2010 conference, a Workshop organized by Paula R.L. Heron and Marisa Michelini (with the contribution of Bat-Sheva Eylon, Yaron Leavi and Alberto Stefanel) took place and was attended by 25 colleagues from 9 countries. Three different groups discussed the issue for primary, lower secondary, and secondary schools, respectively. As a result, it was decided to form a GIREP Thematic Group on ENERGY that was charged to continue work on the subject both through electronic dissemination and through activities at GIREP conferences. The GIREP 2011 workshop on energy has been focused in particular on the primary school level. It consisted in the presentation of the position paper following the Reims Workshop and of two contributions about the construction of the concept of energy in primary school and in a course of teacher formation. This paper, as part of the Symposium “Teaching and learning the concept of energy from early childhood school through university”, reports on the discussion during the 2011 workshop and presents the points recognized to be important and fundamental for the introduction of the concept of energy at primary school level.

1. The symposium contents.

The 2011 Jyväskylä GIREP conference hosted the workshop “Teaching and learning the energy concept and teacher formation in primary school”, organized and led by Federico Corni, Marisa Michelini and Lorenzo Santi.

The program provided an introduction by Marisa Michelini followed by a synthesis of the Reims Position paper by Lorenzo Santi. Then, as object of discussion, two presentations were done about teaching and learning the concept of energy in primary school by Marisa Michelini and by Federico Corni.

1.1. Contribution by Marisa Michelini, Dorian Colonnese, Paula Heron, Lorenzo Santi and Alberto Stefanel.

Marisa Michelini presented an educational path with 6-12 primary school pupils (other authors were). Each step of the path was intended to lead logically to the “discovery” of a new type of energy or to the exploration of the variables associated with a particular type. At each stage, there was an attempt to direct students’ attention to the transformation of energy from one type to another. The idea of conservation was only hinted at (in a qualitative way) in an experiment, late in the sequence, in which an object bobs on the end of a spring. The intent was to lay the groundwork for a more quantitative treatment of energy in later studies in middle and high school. The sequence contains many activities that allow students to experiment. Most of the apparatuses consisted of toys. Therefore the materials are inexpensive and easy to find, as well as being familiar and engaging to students.
The major goals of the intervention are the following.

1.1.1. Energy exists in different types, synthesizable in the following four: kinetic energy (energy associated to rotational and translational movements), gravitational and elastic potential energy (referred to in the curriculum as “falling” and “spring” energy), internal energy (associated with internal structure and temperature) and energy associated with light.

1.1.2. Energy is an abstract property of a system in a particular condition (a state property, described in everyday terms); not a material substance.

1.1.3. The well-known tendency for pupils to conceptualize energy as a quasi-material substance that can flow from one object to another may be natural, and may encourage the development of the ideas of transfer and conservation, but it is an idea that is not consistent with the contemporary view of energy held by physicists.

1.1.4. Energy concepts need to be invoked in situations in which observable changes are taking place: wheels spinning more quickly, objects falling from higher to lower positions, temperatures increasing, etc. To help the identification of energy type involved in static situations, the initial and final states of the systems must be clearly identified and analyzed.

1.1.5. Since students often associate energy only with effects they can perceive, some cases were considered in which the transformation of energy is partially identified at a macroscopic level (e.g., salt dissolved in water and consequent change in temperature of the water), but assumed to occur at a different level (the chemical processes that are invisible when the salt dissolves).

1.1.6. Energy is a physical quantity that is a measurable property of a system

1.2. Contribution by Federico Corni and Cristina Mariani

Federico Corni presented a proposal for teaching and learning the Energy Concept in Primary School, following the approach by Fuchs et al. (Fuchs, 2012). The idea is that the concept of energy can be built, at primary school level, by analyzing interaction processes starting from the notions of cause-effect and evidencing/differentiating/relating the extensive quantities and the corresponding intensive quantities involved with their variations.

Steps of the path are the following:

• identification of the fall and the rise of the potentials of the extensive quantities involved in an interaction. The pumping of a certain amount of an extensive quantity Q1 through a rising potential (effect) occurs at the expense of lowering the potential of an amount of another extensive quantity (cause).

• recognition of the balanced relation between the quantitative and qualitative variables of the causes and the quantitative and qualitative variables of the effects. The basic concept of energy therefore arises from the identification of the “proportion” between the products of extensive quantities and their potential changes.

Didactic steps following these guidelines are:

1. Analysis of cause-effects interactions (use of simple toys)
2. Evidence of couples of extensive-intensive quantities involved
3. Differentiation of the quantities involved
4. Focusing on the changes of the intensive quantities
5. Recognition of the relation between the extensive quantities and their potential changes

The relevant variables and their relationships are recognized by experimental activities (hands-on) as well as reflection activities (mind-on).
The major discussion points suggested by this approach are:

1.2.1. Energy is an abstract concept, not a substance. Do not rely on common meanings of energy (do not use the word “energy”, etc.), but develop the scientific foundations on which this concept could later be correctly constructed.

1.2.2. The foundation of the future concept of energy for children is summarized in the balance relation:

1.2.3. Physics education in primary school consists in guiding pupils to recognize, differentiate and relate the elementary concepts of extensive quantities and their potential changes.

1.2.4. The elementary concepts of extensive and intensive quantities, relevant for the construction of the above foundation, emerge from the pupils’ language to describe interaction processes.

1.2.5. Interaction processes can be analyzed in terms of cause-effect and their proportion.

2. Issues discussed at the workshop and elements of the position paper after the integration with the primary school specifications.

2.1 Is it appropriate to introduce energy at primary school level?

There is a wide literature that shows that children, in the first explorations of the world, construct ideas about concepts and implicit interpretations that determine the ways of seeing issues.

In the school, teacher invite various experts to treat sustainability, energy conservation, etc. This requires a discussion lead by the teacher to help children develop the language of common sense (energy resources, energy reservoirs and sources, loss of energy, waste, scatter) toward the construction of a physical quantity that is conservative and able to transform into types (kinetic, potential, internal and radiative) rather than into forms (electrical, thermal, hydric, light energy). It is necessary to work in the direction of a connection for the switch from the common sense to the scientific idea of the concept, in order to make a correct interpretation of the terms of common sense.

The forms of energy are those connected to the transformation sites, which children are lead to consider sources. For them, there are substances that supply energy and then that are sources of energy, so determining the idea of form of energy. For children, the wind, for example, can be considered as a form of energy, instead of a type (the kinetic energy of air). Without missing the variety and the diversity of occurrence of the energy concept, that is useful for children to organize their ideas, it is useful to help them to recognize the types subtended by the single forms, in order that a multi-perspectivalness grows functional to the change from the local to the global, from the common to the scientific levels.

2.2 Hints form the discussion about the issues raised by the position paper.

2.1.1. What is energy?

As the literature widely shows, it is inappropriate to try to answer this question with the search for a definition of energy. It is more appropriate to aim to provide a satisfactory functional understanding underlying energy transformation as the site for those that are considered sources of energy in the various forms.

2.2.2. Possible approaches.

- Thinking of energy as cause of events often produces the idea that energy is an entity itself instead if a property of systems.
- It is shared to avoid the idea of energy as the ability to do work, first because in primary school work is incomprehensible, second because this characterization makes sense only in mechanics and it produces the wrong idea just at the age when it should be appropriate to introduce the types energy. A working definition, or rather a characterization as a property of systems that is conserved and that transforms with examples of transformations, seems more appropriate.
• A shared position is that we should deal with cases of transformation either on the operational plan, either in the imaginative reading of kids, in order that the gradual recognition occurs first of the various forms of energy, and then of the way in which the forms can be grouped into types of energy. About the approach of transformations, different positions have emerged. One of them is focused on an operational approach based on the energy change that is the qualitative and quantitative description of the change in a system going from one state to another with a detailed description of the processes and not only of the difference between the states (as it is reported by Reif and Carplus in the literature). Another position argues that it is better to establish a way of thinking in terms of energy transfers between energy carriers (extensive quantities) undergoing potential changes [ref Herrmann]. In both approaches, the idea of telling processes to create a story of arguments as language of reading phenomena seems very effective, because, in addition to base an organic reading of phenomena and of their interpretation, it accustoms to a consistent language in the perspective of making common sense ideas evolving toward the scientific ones.

3. Emerged issues and discussion points.

3.1. It’s good for the children the idea of energy as an entity because for them it is important to have a specific referent. On the other hand this bases an idea that is scientifically incorrect.

3.2. Aware that certain types of energy, such the kinetic energy which depends on the square of velocity, can not be characterized by a simple linear relation, however it seems important to identify a type of energy that can be measured with the children, i.e. the internal energy as in some teaching projects (PS2), or the gravitational potential energy measured by the body weight and the altitude from which it can fall or raise as is done in the HMS (Heron Michelini Stefanel) proposal. This particular type of energy, whatever it is, can become the conceptual reference for the various transformations so that the measures of the other types of energy, reduced to measures of the same type, are useful to highlight the energy conservation.

3.3. It is very important to point out that energy is a property of every system and not only of some of them. Many literature researches evidence that the children idea of energy concerns only livings, machines that do something, or substances like sugar, food and fuels.

3.4. Great importance should be given to the internal energy, recognized as a property of systems related to their temperature, which changes can be recognized and identified by changes in structure and form, as well as in temperature.

3.5. Energy has the nature of an extensive quantity related to the amounts of involved extensive quantities (energy carrier) and changes in their conjugated (generalized) potentials.

3.6. A large number of examples can be used to show that the production and loss of energy can be actually analyzed in terms of transformation of energy

3.7. As reported in literature and as we can easily meet in our experience, the idea of conservation of energy is to be founded in physical terms because children (and adults) have a vision associated with the care and storage of energy in such a way it is not consumed or degraded.

3.8. It seems appropriate to base the concept of energy as a language rather than to tie it to other mechanical quantities such as force and power, to prevent the identification of energy with the force, that results to be a widespread node in children who have faced energy through the traditional route force-work-mechanical energy.

3.9. There is a big job to do, because textbooks associate force to energy, without a criticism of the two meanings in the natural language.
4. Teacher training.

Teachers need to acquire knowledge of a few concepts but in a rigorous way so as to be reassured in front of children. This means:

4.1. Make a large number of examples with associated measurements so as to be unequivocal what is measured, what types of transformations occur, since the context specifies the learning process and offers exemplifications useful for the didactical activity.

4.2. Support teachers in the didactical activities particularly on this issue, also by producing materials that can supply for the deficiencies of textbooks or the interventions of experts whose language, away from that of teaching, can generate misunderstandings about basic concepts while providing socially useful directions.

References


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UNEDLABS - An Example of EJS Labs Integration into Moodle

Luis de la Torre, Spanish Open University (UNED)
Juan P. Sánchez, Spanish Open University (UNED)
Rubén Heradio, Spanish Open University (UNED)
Carmen Carreras, Spanish Open University (UNED)
Manuel Yuste, Spanish Open University (UNED)
José Sánchez, Spanish Open University (UNED)
Sebastián Dormido, Spanish Open University (UNED)

Abstract

UNEDLabs is a web portal of virtual and remote laboratories for Engineering and Science students. It is based mainly on two well-known, free and open source tools: a learning management system (Moodle) and a program that facilitates the creation of simulations (Easy Java Simulations). This paper proposes a methodology for creating web experimentation portals (such as UNEDLabs) and details the use of the, already mentioned, required software tools and their interrelation. This work also describes one of the experiments which have been made operative recently. Finally, we examine our students’ satisfaction with the whole system: the web portal and the complete set of virtual and remote laboratories.

Keywords: Education courses, Distance learning, Learning systems, Web design.

UNEDLABS - An Example of EJS Labs Integration into Moodle

The Anadolu University, the UK Open University and the Spanish Open University (UNED) are the three largest universities (in terms of enrolments) in Europe, with around one million, 250.000 and 200.000 students, respectively. An important factor, apart from the big number of students, is that these three universities are based in distance education methods. This means students are not localized but scattered around their countries or even all over the world. With these numbers and the already described educational scenario, it is understandable that these universities have a great need of distance education resources, methods, and technologies. For example, organizing and preparing traditional hands-on laboratory sessions for students of scientific and technical courses becomes an almost impossible task. Given this scenario, web-based labs may look as a good solution.

Nowadays, web-based laboratories are well established in many technical and scientific fields since they help to visualize phenomena that require difficult-to-assemble or costly equipment, (Sivakumar et al., 2005). Usually, web laboratories consist of one (or both) of these two parts: the simulated experiment and its real (remotely controlled) counterpart. While real laboratories can not just be replaced by simulations, or virtual laboratories (VLs), remote laboratories (RLs), which perform real experiments, may be a better complement or substitute to hands-on experiments. However, VLs still serve as a first contact either with 1) the graphical user interface (GUI) of the computer application (VLs and RLs may share it) and/or 2) the phenomena under study (Hwang et al., 2009).

Some works like the one by Goodwin et al. in 2011 and the one by Christian and Belloni in 2004 present lots of simulated experiments in different fields of Physics. Fraser et al. (2007) used computer simulations are used for enhancing the learning of fluid mechanics. Frances et al. (2012) presented an optical-system simulation software that provides a VL for studying the effects of propagation. Nevertheless, real experiments are not considered in the previous works and only in the last few years, RLs are being more commonly considered, such as in the work by Schauer et al. (2008). However, most of the RLs require individual efforts to create the experiment and are limited to a particular field, such as electronics (Moon et al., 2008) or optics (Gurkan et al., 2008).

Moreover, VLs and/or RLs are not enough by themselves. Distance students require a complete web experimentation portal, qualified for stimulating both practical individual and collaborative work. While VLs/RLs serve for the first, the second can be granted using a learning management system, (LMS). The latter works...
offer neither a Web-enabled environment supported by LMS nor the simulated counterparts of the remote experiments, being one of the main reasons that this integration is neither easy nor quick. Finally, only in some works, such as the ones present by Grober et al. (2008) and by Schauer et al. (2009), each experiment is presented in a traditional way: introduction, theory, exercises, laboratory activities and reference material.

All the previous problems can be summed up in one: there is a lack of structured, easy and standard methodologies for creating and integrating VLs/RLs into a web environment. This work proposes a solution to all these issues by using software tools that let the creation of experimentation portals, like UNEDLabs (http://unedlabs.dia.uned.es) that offers: 1) to their students a set of laboratories that belong to the official curricula of their university’s engineering and scientific degrees and 2) to the instructors a tool (the VRLab plugin for Moodle) and a procedure for easily integrating the laboratories in the LMS web environment. Using the proposed tools and methodology, the experiments in the web portal may not only be simulations but also real experiments. Finally, all these experimentation resources can be accompanied by e-learning resources such as documentation, collaborative and social tools (forums and other communication channels with students and instructors), a private files repository, a calendar that marks the deadlines for the activities, videos and so on.

Focusing on UNEDLabs, several web-labs are either already available or being developed. Each of these labs requires different hardware tools. In order to reduce costs and simplify the construction, some of them were built using LEGO NXT Mindstorms pieces, which offer a nice solution when a limited budget is one of the restrictions to design the experimental setup (Kim, 2011, Gomez et al., 2011 and Pinto et al., 2012). Other setups use aluminum pieces, stepper motors and controllers, force sensors and/or circuit elements. Either way, the hardware is always controlled using LabView or Matlab. Therefore, it does not matter what kind of hardware you use for developing a RL, you will always be able to make it accessible using our methodology.

The present work features a powerful portal along with a new laboratory that serve as an example of how all the previous ones (and any other created using Easy Java Simulations) are and were easily integrated into a web environment powered by Moodle.

This paper gives a detailed description of 1) the proposed methodology, 2) the web portal and its features and 3) the experiences with the thin lens VL/RL. Section 2 offers an overview of the tools and structure used in the methodology proposed by the authors for creating web experimentation portals. Section 3 presents UNEDLabs as a whole, and lists its advantages and features. Section 4 describes the thin lens experiment. In Section 5 students’ assessments are presented and analyzed. Finally, Section 6 contains our conclusions.

**Creating Web Experimentation Portals: Architecture and Tools**

UNEDLabs inherits the well-proven structure of AutomatLabs (Vargas et al., 2008) and FisLabs (de la Torre et al., 2011) for the creation and deployment of VLs and RLs. This methodology is based on the client-server architecture (see Fig. 1) and on Easy Java Simulations (EJS) and LabView or Matlab (see Fig. 2). Fig. 2 shows the communication architecture between the client (the student) and the server (the remote experiment), where arrows going from the client-side sender to the command parser and from the server-side sender to the receiver represent the communication links. The GUI to remotely experiment with these laboratories is an applet, created with EJS, that use the JiL (for LabView) or JiM (for Matlab) modules (Vargas et al., 2009)\(^1\).

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1 These applications can be downloaded from http://lab.dia.uned.es/jil-jim

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Figure 1. Communication is based on the TCP/IP protocol. The server runs the remote experiment while the virtual one is locally running in the client side.

Figure 2. JiL and JiM are two modules developed for communicating EJS with LabView and Matlab, respectively. The VLs corresponding to each remote experiment are also programmed using EJS. EJS is an authoring tool written in Java that helps to create interactive simulations in Java, mainly for teaching and learning purposes (Christian et al., 2011), and lets programmers concentrate most of their time and efforts on the scientific (and not on the technical) aspects of the simulation.

UNEDLabs adds a key tool to this structure; the, according to the eLearning Guild survey¹, most widely used LMS (with more than 58 million estimated users): Moodle.

Therefore, UNEDLabs is a web portal that gathers together the two previous resources (LMS and web-labs), offering an e-learning program based on: 1) experimentation (thanks to the use of the virtual and remote laboratories) and 2) theory documentation provision, social interactivity and easy management (thanks to the use of a modern LMS such as Moodle).

**Methodology Application Example: UNEDLabs**

Next sections depict the advantages, characteristics and features a web experimentation portal developed following our methodology (such as UNEDLabs) offers.

**Advantages for Students**

Thanks to the use of Moodle, in UNEDLabs the material is ordered in courses, offering a clear distinction between the different subjects and categories. Within a particular course, e-learning and experimentation resources are divided into didactical units, which help students to follow an order during the learning process.

On the other hand, UNEDLabs offers a lot of communication channels between students and between students and instructors. Not just emailing options as in FisLabs and AutomatLabs, but also instant messaging to the online users, chats, forums, blogs and wikis. Finally, unlike in the two old portals, there is a private files repository, only accessible for the student that gathered the data contained in the files stored in the repository. Finally, files can also be renamed, downloaded, relocated into new folders and/or shared with other users.

¹ Complete report: http://www.learningsolutionsmag.com/articles/111/
Advantages for Instructors

UNEDLabs uses the VRLab activity. VRLab is a new Moodle plugin developed by the authors to easily add a new VL/RL to any Moodle course. Fig. 3 shows the use of this new feature. In this example, the VL/RL would be included just after the link to the booking system. This is done by clicking on the Add activity list and selecting the new VRLab option. This tool lets instructors to add an EJS applet for virtual or remote experimentation just selecting the .jar file from their hard disk. By this process, the web page containing the applet within the Moodle course is generated and the communication between this Java application and the My Private Files block (for saving graphs and data) is established. This plugin is already available at http://lab.dia.uned.es/vrlab.

Other important new features are the ability to set up deadlines for some tasks (such as completing a test or sending a laboratory report), or the calendar displayed in the web environment (upper right corner in Fig. 4), which helps students to keep in mind those important dates or other possible upcoming events. Conditional access is also an interesting feature since instructors can prepare tests that serve as keys to open the access to a VL, for example. Finally, as VRLab is a standard Moodle plugin, it can be combined in a course with any other Moodle plugins, such as the one presented by Trenas et al. (2011), which is applied to the teaching of the practical content of a basic computer organization course.

A Closer Look to UNEDLabs

Fig. 4 shows the main page for the Experimental Techniques course at UNEDLabs. The course is divided into didactical units which share a common structure:

1. A task protocol detailing the experimental activities that students shall perform.
2. A user interface manual for the VL/RL.
3. A practice guide with theoretical documentation about the phenomena to be studied in that particular unit.
4. A theory test that, once passed, automatically grants access to the VLs/RLs.
5. The VL and the RL of that particular didactical unit, added to the course using the VRLab plugin.
6. A tool for students to deliver their laboratory reports.
Lab Example: Thin Lens Experiment

This section presents one of the many VLs/RLs available at UNEDLabs. Thanks to the use of our methodology, any other VL/RL created using EJS can also be added.

![Didactical Unit](image1)

![VL/RL](image2)

![Files saved With the VL/RL](image3)

Figure 4. Two didactical units within the Experimental Techniques in Physics course of the UNEDLabs portal.

![Diagram](image4)

Figure 5. Explanatory scheme of method 2.

The focal length, $f$, of an optical system is a measure of how it makes light converge or diverge. For a thin lens in air, $f$ is the distance from the centre of the lens to the lens’ focal points. If the lens is converging, $f$ is positive, and its value is the distance at which a collimated beam will be focused to a single spot. The value of $f$, the object distance from the object plane to the lens ($s$), and the image distance from the lens to the image plane ($s'$) are related by:

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

By means of this VL/RL, students can:

7. Determine the focal length of a thin lens (method 1). Users collect several measurements of $s$ and $s'$ when the beam is focused over the screen. Then, using (1) and performing a linear regression, they obtain $f$. 

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8. Determine the focal length using Bessel’s method (method 2). If the distance between the object and image planes, \( L \), is greater than \( 4f \), we can find a second position for the lens in which the beam is also focused over the screen (Fig. 5). These two positions are marked with blue arrows in the experimentation applet. Let \( d \) be the distance between those two positions of the lens, then:

\[
f = \frac{L^2 - d^2}{4L}
\]

(2)

9. Students can compare the precision of measuring the focal length by both methods.

Figure 6. Didactical setup of the thin lens experiment.

Figure 6. shows the didactical setup for this experiment, in which a two axis motorized bench is used for setting the position of the lens and the screen independently. A relay is connected to the laser to switch it on or off when a user connects or disconnects from the RL. A diffraction grating is used to split the laser beam into several rays. Finally, two webcams are used: one for giving a general view of the experiment and another one, situated close to the screen, for watching whether the rays are focused over or not.

Virtual Laboratory

Figure 7. Thin lens VL GUI within UNEDLabs. Method 1.
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Fig. 7 shows this lab working in simulation mode when using the first method for determining $f$. It also shows the integration of the laboratory applets into Moodle. The virtual representation of the system shows a laser at the left part. Next to it, a diffraction grating splits the laser beam into several rays. The lens and the screen are the other elements over the rule. Users can change their positions moving their corresponding sliders or clicking with the mouse over the visual element and dragging it. There are two views of the screen: a side one and a front one (represented by the white rectangle). In this last view, students can check if the rays focus over the screen or not. Fig. 8 shows: 1) the tool for performing linear regressions with the collected data and 2) that same data collected during the experimentation with method 1. In the left image the result obtained for $f$ by means of the linear regression is displayed.

Graphs and data can be saved into .jpg and text files, respectively. This is done by pressing the Files repository button on the top menu of the application (left image of Fig. 8). In this experiment, two files are saved and sent to the My Private Files Moodle block, with default names Lentes1Sim_graph_1.jpg and Lentes1Sim_1.txt (these files appear in the block in Fig. 10).

Fig. 9 shows the VL when the second method is being used. In the left image, the first of the two Bessel’s position is found and marked. In the right image, the second one is found and the value of $f$ is determined by means of equation (2). As expected, the results given by both methods are very similar.

**Remote Laboratory**

RLs are operated by means of the same application as the VLs. Students must click on the Connect button (marked with a red circle in Fig. 9) for changing from the VL to the RL. A booking system checks if that user has a reservation to access that particular RL for that day and hour. If that is the case, the GUI changes
and shows the view associated to the RL. Fig. 10 shows a snapshot of this web-lab working in remote mode when using the first method for determining \( f \). Note that the user interfaces are almost identical in simulation and remote modes. Also note that the files saved in the step taken in Fig. 8 are now present in the My Private Files block.

**Figure 10.** Thin lens RL GUI within UNEDLabs. Method 1.

Fig. 11 is the equivalent of Fig. 9 for the remote mode. The two Bessel’s positions are found and marked and therefore, the focal length is determined. When preparing the laboratory report, students are asked to estimate the errors in the measurements and compare the ones obtained for each method in remote mode with the ones obtained in simulation mode.

**Figure 11.** Thin lens RL GUI. Method 2. Blue arrows mark Bessel’s positions.

**Students’ Assessment**

This portal was tested by 20 of our students during their first grade year. They were granted access to the laboratory presented in this work for four months. They were asked to fulfil an opinion poll with different questions about their experience with this system. In this opinion poll, they were asked to mark several statements with numbers from 1 to 5, being 1 that they completely disagree with the statement and 5 that they completely agree with it. Four of the more important questions and answers are shown in Fig. 12, where \( Q_i \) are:

1. **Q1:** Overall, I am satisfied with the clarity and easy of use of the system and the environment.
2. **Q2:** I was able to solve all the tasks only using the material given in this system.
3. Q3: The simulation (VL) has served to make clearer how to work with the RL.

4. Q4: Overall, I am satisfied with this way of performing the experimental activities.

Q1 presents the best results with a 45% of students that completely agree and a 30% that agree with the statement, which means that UNEDLabs seems to be clear and easy enough to use for our students even considering that they follow the course in a very autonomous way. Q2 shows that almost all the students were able to resolve the experimentation tasks without any other help than the one given by the material provided in UNEDLabs, which proves that the portal is suitable for distance education purposes. Q3 reveals the importance of simulations as a first experimental contact for the students in order to make clearer the use of the RL for 70% of the students agreed or completely agreed this statement and only 5% of them disagreed. Finally, Q4 may serve as a conclusion of the whole opinion poll: 75% of the students agreed or completely agreed that UNEDLabs satisfied them as a way to perform the experimental activities.

![Figure 12. Students answers to questions about their perception of UNEDLabs.](image)

**Conclusions**

This paper proposes a methodology for creating web portals in Moodle that easily embed VLS/RLs created with EJS. Theory lessons, grades and reviews by instructors can be easily added thanks to the LMS. A web portal (UNEDLabs) and a VL/RL (the thin lens experiment), created with this methodology, were presented as examples. The only required software tools are: EJS, Moodle (with the VRLab plugin for adding the EJS laboratories and automatically connecting them with My Private Files block), the JIL or JiM applications and LabView or Matlab for controlling the hardware of the experiments.

Data collected during their simulated and real (remote) experiments can be saved in the cloud and accessed through the web portal thanks to the VRLab plugin. Having these data, students can compare the theoretical results with the real ones, which constitutes one of the fundamental issues of the scientific method. This work showed a VL/RL for determining the focal length of a thin lens. Others are already available (DC motor, a three coupled tanks system, a heat flow system...) or in development (a RCL circuit, rigid pendulum, etc). All these experiments (with both VLS and RLs) are easily integrated into UNEDLabs thanks to the VRLab plugin and because they all use the same structure and software tools, even though the hardware is different.

**References**


Understanding the Effects of the Light Propagation with a 3D Virtual Environment: a First Step to Grasp the Special Relativity

C. Maisch*, Université Paris Diderot, Paris 7, Laboratoire de Didactique André Revuz
I. Kermen, Université d’Artois, Laboratoire de didactique André Revuz
C. de Hosson, Université Paris Diderot, Paris 7, Laboratoire de Didactique André Revuz

*Corresponding author: Clemmeche@yahoo.fr

Abstract

Observation of effects directly related to the Special Theory of Relativity (STR) of objects in everyday life is impossible. Actually these effects can only be attested due to travelling at speed near of the light velocity, \( c \). Virtual Relativity (VR) allows us to visualise those effects with a 3D immersive environment. In this paper, we presented results of a new study about how users may understand visual effects macroscopic objects travelling near the speed of light. We managed this visualisation using a 3D simulation of a billiard. We especially looked at the effects due to the light propagation and the ones that could be explained through the Lorentz transformations. Five users with different curricula about physics have been tested inside this environment.

Five conceptual elements have been defined to describe the users' reasoning explaining the effects they observed in a physics way. The first result of this study showed that the users were able to consider the duration of the light propagation, and to localise an event in space and time, thanks to the observed effects of the environment such as: non-simultaneous events, changing in visible velocities, or objects warping. Thus we supposed, they could be able to understand relativistic effects. But the second result showed that they have difficulties to link their observations to issues of the special relativity such as Lorentz transformations (length contractions and time dilation).

The EVEILS project and the education of Special Theory of Relativity (STR)

Special theory of relativity (STR), as introduced by Einstein, is one of the most important revolutions in the history of physics, because the relativistic structure of the spacetime cannot be grasped through a direct, sensible human experience (Einstein and Infeld, 1938). Thus, the observation of effects due to a relativistic velocity is not possible in everyday life. To be able to make such observation we should move at a velocity near the speed of light, which is finite and the value of which is defined as \( c = 3.10^6 \text{ km/s} \). Virtual reality (VR) enables to visualize those effects by means of a 3D immersive environment in which the speed of light can be reduced to usual values. The goal of the EVEILS (French acronym for Virtual Spaces for the Education and Illustration of Science) project is to design a simulator of Virtual Reality (VR) on STR to allow users to grasp these phenomena.

The studies dealing with students’ difficulties about STR (de Hosson et al., 2010; Scherr et al., 2001) are focused on the notions of event and of reference frame. They claim that the understanding of the concept of an event\(^1\) is fundamental to grasp the STR. Indeed this theory is based on the identification of spatiotemporal coordinates of an event in several frameworks of reference. In a given framework, an event is defined by an instant in time and a place in space. But the instant, at which this event is observed, depends on duration of the travel of the light from the spot the event occurred until its arrival to the eyes of the observer. Therefore, two simultaneous events, in a given reference frame, could be observed as non-simultaneous because the travel of photons coming from two different places do not have the same duration. In these studies students predict the classification in which two events are produced through the order these events are perceived by a given observer. Thus researchers concluded that this kind of reasoning might be due to the fact that students do not correctly link distance and time taken by light to travel that distance. Indeed, they do not build the history of a photon in a relevant way. It seems that students use spontaneous reasoning previously detected in classical kinematics (Saltiel and Malgrange, 1980) to understand relativistic situations (Villani and Pacc, 1987).

\(^1\) An event is defined as a fact localised at a given place in space and a given instant in time.
To allow the users to notice this effect and to build a correct history of the photon, we suggest to solve the issue of travelling at a speed near to c. Techniques of virtual reality can allow to simulate such movements and thus to observe effects explained by STR such as the one calculated through the Lorentz transformations (de Hosson et al, 2011). The group of Savage et al (2007) and the one of Rüder et al (2008) carried out a similar project. The first one developed a computer simulation in which a space vehicle could move at a speed close to the one of light. The user could then observe clocks placed regularly beside the vehicle trajectory. He/she might notice the time dilation between the reference frame of the clock and the one of the vehicle. The main particularity of our project lies in the collaboration between researchers in virtual reality, a researcher in astrophysics, and researchers in physics education. The simulator designed by the researchers in VR takes the form of a billiard room inside a CAVE1 (Cave Automatic Virtual Environment) (Doat et al, 2011). Our goal is to explore the cognitive modifications in the users’ reasoning and the pedagogical advantages associated with the simulated environment. In our environment the time signal travels cannot be neglected (c is fixed to 1m/s), thus mundane objects are not seen as in everyday life. Thus this paper is focused on the following issue:

May the sensitive experience of visual consequences of relativistic velocities have an impact on the understanding of the concept of event?

The aim of our study is to verify if the observation of counterintuitive visual effects in a virtual environment, where macroscopic objects are moving at speeds close to that of light c, allows the users of the simulator:

a) To build history of photons arriving to their eyes and thus to accept to consider that the light propagation introduces a time delay. This delay is due to the travel of light from an object to a receiver, here identified as an eye.

b) To access to the « emission » (reflection of photons on a point of an object) event and thus to be able to identify the emission locations for an object changing in time and space.

c) To locate this event as a point in space and time. It corresponds to the identification of an event with a single dot in space and time.

d) To dissociate the effects explained by the light propagation and the ones explained only by SR. Accordingly students would have to recognise that the light propagation is not the only reason for the warping of the observed objects.

**Method**

**The situation**

With the help of the two engineers in virtual reality and the astrophysicist, we implemented a situation in the simulator, that is, a carom billiard. In this situation, a user could move virtually in a billiard room represented in the CAVE. Therefore, one has to move physically between three walls of screens on which the billiard room is projected.

The key innovative aspect of this situation is that the speed of light is fixed to 1 m/s. Additionally the motions and shapes of the objects and the motions of the observer are calculated with Lorentz transform according to the value of c under. The main issue of our study is to make the geometrical effects due to relativistic velocities visible. Thus we did not implement Doppler effect, which involves wavelength modifications that are not specific to STR.

In this billiard, balls are represented by pucks in order to get a better observation of the shape distortions. These pucks move without friction and the collisions with each other or with cushions are elastic. In our experiment only two pucks exist on the table. They are launched automatically at the very same moment from the middle of the table with the same velocity and direction.

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1 RV projection system is based on screens and sound surrounding. Immersion illusion is created with 3D graphic projections. It is coupled with a tracking system of the user’s head. Thus, a complete stereo perspective could be done and the position and the orientation of the user can be isolated to allow him to explore the virtual world by moving inside a cube and manipulating objects.

*WCPE 2012, Istanbul, Turkey*
Participants

This explorative study was carried out with 5 users. They have been chosen because they attended a different education:

- CG: second year master student in physics,
- IEM: second year master student preparing a competitive exam to be physics teacher,
- JO: first year master student preparing a competitive exam to be physics teacher,
- CP: student engaged in a technical education for computer sciences,
- RM: physics researcher specialised in theoretical physics.

Moreover and more important for us, these users had different education about STR: some attended courses in STR (CG, IEM, JO, and RM), and even RM said working with STR sometime. Only CP did not have any education about STR, but is interested in astrophysics.

The three steps of the experiment

The experiment is based on three steps. Those bring into play effects due to the light propagation that users have to identify and to explain from a physics standpoint and effects due to the relativistic velocity.

Table 1. The three steps of the experimentation in our virtual environment

<table>
<thead>
<tr>
<th>Step</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1:</td>
<td>Non-simultaneity observed when the pucks collide with cushions</td>
</tr>
<tr>
<td>Step 2:</td>
<td>Visible differences of speed depending on the direction of the movement of the pucks</td>
</tr>
<tr>
<td>Step 3:</td>
<td>Distortions of the shapes of the observed puck such as contraction and inclination</td>
</tr>
</tbody>
</table>
In the first step, the observer can move along the large cushion of the billiard to modify the distance between him/her and the two collision events, and thus, the time delay between the two collision events. Indeed, the time for the light to travel from an event to the eyes of the observer varies depending on the distance of this event to him/her. Thus, we assume that the observer could notice the influence of the distance between him and the objects and then consider the speed of light as finite.

In the second step, the observer modifies his point of view by moving along or standing in front of the cushion on which the pucks bounce off. It seems to the observer that the pucks come towards him/her faster and faster, while when they are moving away, they seem slowing down. Actually, the phenomenon one observes is due to an increase of frequency of photons arriving from the pucks towards one’s eyes.

In the third step, the observer has to move all over the billiard and to stand at fixed positions. He can freeze the scene and then move again in the frozen scene to observe the shape of the objects. Here once the scene is frozen, the shape and position of each object correspond to the ones calculated according to the position of the observer when he froze the scene. The observer can then see the distortions of the object such as: contraction, elongation, and also see its inclination.

The expected explanation deals again with the light travel time depending on the distance between the emission place and reception place. The difference with the two previous situations is that the users, to be able to explain these distortions, have to describe an object as a set of points, distant from each other, from which light would be emitted. Thus, photons emitted at the very same moment at different locations (points) will arrive to the observer’s eyes at different moments. The observed image would be the composition of photons emitted at different moments. This is notably different of what we are used to observe in usual life. Therefore the user needs to specifically localise the « emission » event in both space and time. This is an important change from the usual way to identify the position of an object by its position in the space in everyday life. We consider that this breaking out of the object in dots and their localisation in space and time are essential for the understanding of these effects.

Picture 1. User in the CAVE (CNRS/LIMSI, Orsay, France)

Analysis procedure

The users came into the simulator and their comments have been audio-recorded and then transcribed to allow us to make a lexical analysis.

We looked for five conceptual elements (CE), which were defined as necessary for a correct reasoning to describe the effects observed in the simulation according to physics. In each step we determined elements we think students would prone more to speak about:

1. Entrance of the light in the eye (steps 1,2,3)
2. Finite characteristic of the speed of light (steps 1, 2, 3)
3. Object-observer distance (steps 1, 2, 3)
4. Punctual breaking down of an object (step 3)
5. Effects explained with Lorentz transformations (step 3)
Results and discussion

Entrance of the light in the eye, finite characteristic of the speed of light and distance between the object and the observer

Table 2. Using of the first three conceptual elements

<table>
<thead>
<tr>
<th>Conceptual Elements</th>
<th>Users quoting CE in step 1</th>
<th>Users quoting CE in step 2</th>
<th>Users quoting CE in step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance of the light in the eyes</td>
<td>CG, IEM, RM, JO</td>
<td>CG, CP, IEM</td>
<td>CG, RM, JO</td>
</tr>
<tr>
<td>Finite characteristic of the speed of light</td>
<td>CG, IEM, RM, JO</td>
<td>RM</td>
<td>CG, JO</td>
</tr>
<tr>
<td>Objects – observer distance</td>
<td>All</td>
<td>All</td>
<td>All</td>
</tr>
</tbody>
</table>

Regarding the first three conceptual elements described previously, we found a sign of them in each of the users’ explanation in at least one of the steps. Furthermore an explanation about the distance between the user and the objects is present in each step for every user, when the finite characteristic of light is mainly present in step 1. This may be due to the fact that the users repeat in different steps descriptions dealing with the same conceptual element, when they need to describe a similar effect.

Example of the presence of these conceptual elements for the user JO, in step 1 (the underlined sentences are the ones fitting with a conceptual element):

« It would be due to, hum, to the fact, the speed of light is finite, and if, if the distance to travel is bigger I see, hum, I see a delay, indeed, I perceived a delay. So photons take more time to, hum, to arrive to my eyes. »

Here, we classified JO’s talk in such a way: «the speed of light is finite» deals with the finite characteristic of the speed of light, «if the distance to travel is bigger I see, hum, I see a delay, indeed, I perceived a delay.» deals with the distance between objects and the observer, and « Photons take more time to, hum, to arrive to my eyes.» deals with the entrance of light in the eyes. This example shows that the identification of the three conceptual elements in the users speaking is not ambiguous. Finally we notice that JO’s example, using the three CE in one sentence, is really unique for our sample of users. The other users said each CE at different times in different sentences.

Finally, these results show that the users localised and described easily all three conceptual elements listed above in the three steps. Thus we can suppose that these three steps allow the five users to identify where the light is received, to consider that the travel of light is not instantaneous because the light has a finite speed, and finally that the distance between an object from which the light is coming and the reception point (the eye) may have an impact on what can be seen in the simulator.

Punctual breaking down of an object

Table 3. Using of the fourth conceptual element

<table>
<thead>
<tr>
<th>Conceptual element</th>
<th>Users quoting CE in step 1</th>
<th>Users quoting CE in step 2</th>
<th>Users quoting CE in step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punctual breaking down of an object</td>
<td>None</td>
<td>IEM</td>
<td>All</td>
</tr>
</tbody>
</table>

The analyses on the punctual breaking down of an object showed that the users do not feel the necessity
to speak of the emission of light at one place and one moment from an object in the step 1 and 2. IEM is the only user, who gave an explanation following this conceptual element in step 2.

When we look at what CP said in step 3, we can see a part of his strategy design in which he breaks down the object in several points.

“That’s the front [of the puck] is younger [than the rear], it had time to travel some distance before, hum, the photon that I’m looking a , has been emitted. [...] from my point of view, the rear wasn’t at the same place at the very moment of the emission. It was rear, which gives it a stretching effect. What I see, it has different emission moment, the front and the rear of, of the puck.”

The main description, following this CE, describes the reason of the warping and inclination of the pucks. Actually the majority of the description of the breaking down of an object fits with the distinction of the emission moment of two ends of the objects (top and down, rear and front).

Finally IEM shows that a strategy, to describe the effects observed dealing with a punctual emission of the light as photons could be built in the second step, but he is the only one to do it. The main result is the relevance of the third step to lead users to build this strategy. Indeed all users described the effects following a similar strategy, when they have to describe the warping and inclination of the pucks on the billiard.

**Lorentz transformations**

Concerning the last conceptual element we were looking at, none of the users made an appropriate use of the Lorentz transforms.

**Table 4.** Using of the fifth conceptual element

<table>
<thead>
<tr>
<th>Conceptual element</th>
<th>Users quoting CE in step 1</th>
<th>Users quoting CE in step 2</th>
<th>Users quoting CE in step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects explained through Lorentz transform</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

This result is one of the strongest of our study. An account for this result could be that descriptions dealing with the light propagation took a large part in users’ thoughts, which did not help them to suggest other explanations. This result underlines the significance to make users understand, first, the issues and effects due to finite characteristics of the speed of light and, second, the localisation of events in time and space before describing the effects due to the STR.

**Doppler effect**

The following table presents explanations dealing with other issues and considered as off-topic such as the Doppler effect.

**Table 5.** Using the Doppler effect explanation

<table>
<thead>
<tr>
<th>Conceptual element</th>
<th>Users quoting CE in step 1</th>
<th>Users quoting CE in step 2</th>
<th>Users quoting CE in step 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler effect</td>
<td>IEM</td>
<td>CG, IEM, RM</td>
<td>RM</td>
</tr>
</tbody>
</table>

Interviews after experimentation showed that the users, who learnt STR elements, are the only ones who speak about the Doppler issue. We would like to remind that the Doppler effect according to the wave characteristic of the light has not been implemented for observation reason. In this context, we notice that
RM quoted the Doppler effect with a conditional form in his description and came back later to it even if experimenters (us) explained him that the Doppler effect had not been implemented.

« It’s partly, hum, I would say, it’s almost a Doppler effect, hum. When the, hum, the object, which emit light, come closer to me, hum. I don’t know if a Doppler effect, neither, when the object come closer to me, I feel it’s going, hum, it’s coming really faster than when it’s going away. »

The presence of explanations involving Doppler effect could be surprising as nothing has been said or indicated to lead to this reasoning. Thus we can only suppose that Doppler effect is representative of the STR for users who have been taught STR. It would be interesting to know better how these users link the Doppler effect to the STR and why.

**Conclusion**

Our 3D environment allowed 5 users to make use of reasoning concerning light propagation and involving:
1. The necessity for the light coming from the pucks to reach the eyes of the observers,
2. The finite characteristic of the speed of light, or the distance between each point of the pucks and the eyes of the observers.

They have also been able to build reasoning involving the punctual breaking down of objects and to consider each point of the object as a punctual light source The use of such conceptual elements illustrates the fact they have been able to build the history of a photon from its start from the object to its incoming in the eyes of the observer. The users also showed that they have been able to identify an event (e.g. the emission of a photon) as a single dot localised in space and time. Therefore they have been able to identify every effect due to the fact that the light propagation must be taken into account. Conversely the effects according to the STR were not identified in a relevant way. Actually, most of the videos dealing with STR show what we would see if no observer would be present in the scene (and thus ignore his influence toward the environing objects). Thus, the interviewed users were probably expecting to be confronted to usual STR visual effects such as “length contraction” as presented in a lot of science popularisation tools and videos. Nevertheless, in our environment these effects cannot be visualised for themselves. From the moment when an observer is present into the VR-scene, the shape and the velocity of an object are calculated taking into account the Lorentz transform AND the delay taken by one photon to pass from an object to the eyes of the observers. These non-expected visual effects are used in order to make users trace the history of the photons, and to link properly two distinct events: “reception of a photon into the eye” and “emission of this photon from a given dot”.

**References**


*Proceedings of The World Conference on Physics Education 2012*

Science at School at a Distance of a Click

Rosa Doran, NUCLIO – Núcleo Interactivo de Astronomia
Telma Esperança, Observatório Astronómico de Coimbra
João Fernandes, Observatório Astronómico de Coimbra,
(on behalf of the Discover the Cosmos Consortium)

Abstract

The field of science education is a continuous challenge to educators around the globe. New technologies, in this fast changing digital era, are opening the way to learning trajectories based in the use of real research based methodologies. At the same time educators in schools around the world are fighting the lack of interest on the part of young generations. This fast growing gap between the available tools and resources and the demand of science knowledge on the part of students must be quickly addressed. Educators must be prepared to engage in a totally different approach for science teaching. A new era of tools, adapted to classroom curricula is emerging. Science empires are opening their database and producing user friendly interfaces to be used in schools. In this paper we will discuss the approach being adopted by the Discover the Cosmos consortium (an European Commission funded project) to engage students and teachers in research based science education. Participants find in this project a place to discuss their needs and limitation as well as an open dialogue space to share their vision and ideas. Members of different communities are gathering around Europe to design a new model for the road ahead. Facilities like CERN are contributing by making their repositories available to this mission. Robotic Telescopes are integrated in the proposed resources and exercises integrating the science method, while using new technologies, are a key part of this proposal. DtC is a two years pilot study, started in 2011, to validate and evaluate the use of several refereed education scenarios in 8 European countries. It is a 2 year project that will reach over 700 schools and 5000 teachers, during the duration of the project, in the large scale pilot trials. The refereed scenarios and the ones created by the community of users will be integrating part of the Discover the Cosmos Portal.

Introduction

Science education is a field attracting the attention of social sciences researcher, science institutions, educators, politicians, parents, etc. It is an area of knowledge that enters deeply in our daily lives but not in our common senses. New generations are being born in the era of tactile information but never before the interest in what lies behind the possibility of having such technologies was so low. Students in general fear STEM topics and diverge to other areas when choosing their careers. Nowadays “having” has a stronger weight in student’s choices for future careers than “knowing”. Studies such as (Bonga, 2006) and (Svein Sjøberg, 2010)) show a clear trend against following scientific careers with a stronger trend in girls than in boys and more clearly visible in developed nations than developing countries. Further stills it clearly shows that students from those countries that perform very well, like Finland, are not willing to pursue a career in science.

The problem might be deeper than what we see in the surface, even students that score high in STEM disciplines exhibit lack of proper understanding of basic science concepts and not capable to transfer the learning experience to other areas (Dixon and Brown, 2012).

The Rocard Report ((Michel Rocard (Chair), 2007)) points out that in many cases the factor impacting these lack of interest of performance is the methodology used and sometimes the lack of proper preparation on the side of educators. In fields like Astronomy for instance this problem can be aggravated by the fact that many teachers never received training in the area and don’t feel confident enough to address cutting edge topics of science.

Another issue worth mentioning is the fact that new technologies are opening knowledge opportunities with a completely unprecedented speed. Students can be swamped with information and learning experiences that are very appealing such as citizen science programs, simulations of real science.
experiences at a distance of a click, TV series bringing science with high quality visuals and skilled actors, games simulating real life situations, etc. All this fountain of information can stimulate the creativity and interactivity, provoke their curiosity but might at the same time cause the lack of interest for school and the way new learning opportunities are offered.

Discover the Cosmos is an European Commission funded project under the FP7 Research Infrastructures call. The Discover the COSMOS coordination action aims to engage students and teachers in research based science education. To demonstrate innovative ways to involve teachers and students in e-Science through the use of existing e-infrastructures in order to spark young people’s interest in science and in following scientific career.

Tools and resources

DtC is bringing to classroom einfrastructures such as CERN, robotic telescopes facilities, observatories, etc. Best practice resources such as Salsa J, an (image processing software created by the European Hands-on Universe Consortium-(EUHOU, 2004)), Sun4all (a collection of exercises that promote the use of a repository of solar images taken by the Astronomical Observatory of Coimbra - (OAC)),

The tools, resources, infrastructures and partners

Research infrastructures, archives and databases are made available to schools. The tools are coming from:

- CERN (LHC, CMS, ATLAS)
- Faulkes Telescopes (Hawaii & Australia)
- DSPACE Telescopes (Europe and Chile)
- COSMOS Scientific Repository for Science Education
- Learning with ATLAS Repository for Science Education

DtC is piloting a few efforts that aim to help teachers make sense of the use of infrastructures and databases such as CERN, Faulkes Telescope and repositories of data such as Sun4all. eScience environments are being offered in the framework of DtC:

- HYPATIA, AMELIA, MINERVA (Data Analysis Tools for particle detectors)
- SALSAJ and IMAGEL (Analysis Tools for Images from Telescopes)
- Interfaces for operating Robotic Telescopes
- Virtual Visits and Demos

Discover the Cosmos will help educators build effective lesson plans where the use of freely available tools and resources, that resemble the actual research environment and reproduce the scientific method, can be perfectly integrated along with the curriculum directives. Students will learn how cutting edge scientific discoveries are made by using environments such as HYPATIA or Minerva. They will be able to observe the Universe live using robotic telescopes and datamine science archives like for instance studying the Sun’s activity using the Astronomical Observatory of Coimbra’s data archives (dating back to 1926).

Community

The sustainability and legacy of DtC depends upon an effective involvement of the community of users. The Galileo Teacher Training Program (GTTP, 2009) model for developing a community is being used in DtC. The strength of GTTP, with representatives in over 100 nations and having reached over 15 000 teachers globally, relies on the continuation of the support mechanism. The strategy is followed in several steps:

- Engage students in real research experiences by introducing best practice examples (DtC Demonstrators)
- Empower teachers for the use of eScience tools and resources via workshop and a continuous support network;

WCPE 2012, Istanbul, Turkey
- Promotion of collaboration between teachers;
- Promotion of collaboration between teachers and researchers.

A key part of DtC strategy for effectively involving the community is the promotion of several interactive and reflection moments. Through the promotion of Visionary and Practice Reflection workshops teachers have the opportunity to share their concerns and share their ideas and suggestions. With this strategy they become part of the solution and active promoters of the foreseen innovation.

When the teachers question themselves and question the contexts / learning environments and practices, in a logic of reflection-action-reflection permanent and systematic process, the collection and production of valid information to base strategies / activities of learning will develop. If the teachers have the responsibility for deciding what changes are necessary and their interpretations and critical analyzes are used as a basis to monitor and evaluate, process get increases in efficiency and quality product. (Ainscow (2000).

The support to educators range from face-to-face and online training sessions to school visits where the innovative approach of DtC can be demonstrated to students and other colleague (DtC@Schools). In Portugal for instance over 30 schools where involved (nearly 100 teachers and approx.. 1500 students).

**The Methodology and the curricula**

Empowering teachers is an important step on this journey but far from being enough. Practical solutions and examples need to be designed and presented during several training workshops. Teachers need to gain confidence on the usability of the tools being presented and it must fit into the curricula. Materials need to be easily localizable to the local needs and should have been successfully tested by skilled teachers before.

**IBSE**

The methodology adopted to build the real research scenarios is based on the guided inquiry method (Kuhlthau, 2010). In this methodology students reproduce the scientific method by following the same cycle as scientists use in their research. Knowledge is constructed through experimentation, discussing ideas with teachers and peers and direct interaction with the scientific phenomenon (Allende 2008). Several education experts, in the United States, believe that IBSE is the basis of scientific learning (National Research Council, 1996, p.5, cited by Ebenezer et al 2011) and is an internationally methodology (Council of Ministers of Education of Canada, 1997; Department for Education and Employment 1999, cited by Ebenezer et al 2011).

By introducing certain specific topics using this methodology we can optimize the learning curve of the student while awaken their interest for science topics and increase their will to learn more. Bellow some examples on how such innovations are being applied in DtC demonstrators:

**Planetaria Software:** Interactive tools that simulate the sky and demonstrate the celestial movements. Such applications help students understand important phenomena while investigating the different features available and proposing and testing their own hypothesis. Students can for instance explore the movements of the Moon and Sun and how the interaction of the Sun-Moon-Earth causes the different phenomena we observe. A night sky observing session can be planned and target objects studied in order to prepare a research study. Some planetaria software provides access to astronomy imagery taken by professional quality telescopes. New science outcomes can come out of the exploration of such images.

**Data Mining** – Image archives from the major science laboratories are now available on the web. Users can have free access to a vast amount of data, ready to be explored. New science discoveries are now awaiting anyone willing to explore such possibility. This data archives are being transformed in citizen science projects were students can contribute actively to the researcher’s community. We can name as examples : Sun4all (that uses the Astronomical Observatory of Coimbra’s images), CosmoQuest (that uses NASA’s missions data), or the Astronomical Search Collaboration where students look for unknown minor bodies of the solar system among others.

**Robotic Telescopes** – With the use of such equipments, telescopes that can be remotely controlled, students can prepare their own research projects and observe a selection of objects. They can for instance study the life cycle of stars or the composition of our Universe while acquiring important planning and inquiry skills.

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The Consortium

The DtC consortium is composed by 15 partners from 7 different European countries and one partner from the US. Members come from two main fields: particle physics and astronomy. Research infrastructures are provided by CERN, Observatory of Coimbra, IASA, Univ. of Glamorgan (Faulkes Telescope), Cambridge University and Liverpool John Moores University. The eScience applications and environments come from: Institut d’Astrophysique de Paris, Univ. Dresden, Univ. Birmingham, NUCLIO and Ellinogermaniki Agogi. This diverse selection allows the implementation of a rich selection of demonstrators and the support of experts in the different areas ranging from particle physics to science education.

Conclusions and Discussion

The presentation of demonstrators during visionary workshops and training events was greeted with great enthusiasm by the teachers. However, in some countries, Portugal for instance, they manifested concern regarding the time required to implement such models in schools. In some cases the lack of ICT literacy and equipments is also a concern. The adaptability of the proposed applications to school curricula a major need. DtC at the present stage is still in the phase of piloting in schools and will still undergo several cycles of discussion and reflection before we can draw a deeper conclusion on the effectiveness of the approach.

In the first year of the project, in the 8 countries of DtC Consortium over 450 events were promoted and 1700 teachers reached. These numbers were achieved with the promotion of Visionary Workshops, Training Workshops, Dissemination events, etc.

In the portal we can find 114 Demonstrators (in the different languages of the Consortium).

In DtC we intend to walk hand in hand with teachers, training them on the use of modern tools, helping adapt inquiry examples in curricula topics and evaluate the impact in the learning of students. The new era of education is clearly emerging where educators have to assume the role of tutors of this fast growing digitally skilled generation. The possibility of science discoveries are now at a distance of a click, students must assume this responsibility.

References


Magnetic Field Nature and Magnetic Flux Changes in Building Formal Thinking at Secondary School Level

Marisa Michelini, Research Unit in Physics Education of the University of Udine, Italy
Stefano Vercellati, Research Unit in Physics Education of the University of Udine, Italy

Abstract

The importance of the electromagnetism as topic itself and educational framework in which learn how to master multivariable abstract entities require the development of organic learning path for high school students. An empirical research done in the framework of a designed based research was performed in three different types of high schools to look at the reasoning that an organic learning path constructed on the formal construction of abstract entities promote in the students when the idea of the flux tubes representation is introduced as the key element in the interpretation of the magnetic field representation. The learning path, designed with an inquired based approach, provide to students the environment in which experimentally explore physical quantities constructing formal entities able to represent their properties. Then, the providing of challenging context, as the explanation of the processes of electromagnetic induction, allows to investigate how students validate and/or extend their interpretative model based on the constructed formal entities.

Introduction

Electromagnetism is one of the main topic addressed in the last years of the high schools and has an intrinsic importance in the understanding of several everyday phenomena. Research literature widely addressed the main learning knots related to this topic: the field representation (Guisasola et all, 1999), the field as a superposition (Viennot & Rainson, 1992), the relation between magnetic field and electric currents and the nature of field itself (Thong and Gunstone, 2008), the sources of field and the role of relative motion in the electromagnetic induction (Maloney et all, 2001) and the identification of the versus of the induced magnetic field (Bagno & Eylon, 1997) but there is a lack of proposals of organic learning path that cover all of them.

A first attempt to face this issue was proposed by Bradamante et al. (2005) using the field lines of the magnetic field as conceptual referent for the magnetic field representation. Looking at this particular angle of attach, in the framework of a Design Based Research, an organic curricular proposal was developed providing to students a specific learning path that, using inquired based tutorials, overcome the intrinsic qualitative nature of the field lines representation proposing the operative construction of the flux tubes as the way to construct the key conceptual referent for the exploration of the electromagnetic phenomena. In this approach, the idea of flux is constructed not only on a formal level but also on the conceptual plane, becoming so an operative conceptual referent which changes over time produce the phenomena of electromagnetic induction.

In particular, to investigate the students’ reasoning promoted by the use of this learning path, the following aspects were addressed: How did the students construct the idea of field so that it could become an organic entity of reference (RQ1); When and how the concept of field become a conceptual referent in students’ reasoning (RQ2); What is the role of the experimental exploration in building formal interpretative models of the electromagnetic induction (RQ3).

Methods

In the framework of a co-planning work to promote the innovation of the teaching strategies in the Italian high school, the experimentation of the learning path was carried out by a researcher in three high school classrooms at the presence of the school teachers. All the classes involved are grade 13th (students are mainly 18 years old) and are selected from different types of schools to test the portability of the learning path: one classical lyceum, one linguistic lyceum and one scientific technological lyceum. The experimentations were held in the schools in accordance with the standard time table of the involved classes using a total amount of 12 hours of lessons.
The proposed learning path was structured by means of a context related approach in which particular experimental situations are proposed as starting points of phenomenological investigations in the framework of a gradual grow of the level of formalization for the interpretative quantities adopted. The whole summary of the inquired learning based tutorial and the learning path are reported in detail in Appendix A. In this paragraph will be discussed the steps of the learning path exploiting the rational on it takes grounds.

The learning path begins with very simple situations presented as introductory activities aimed to recall student’s everyday knowledge as regards the exploration of the simpler magnetostatic interaction between objects. In particular, a box full of everyday objects of different types is proposed to the students and was asked them to individuate the magnets in the box, describe the different type of interaction they experiencing between the objects of the box and categorize the object by the types of interactions (activities 1-4 – Appendix A).

During these activities, as during the other ones proposed among the learning path, individual and group works are alternated to share and compare the findings inside the class.

Then (activities 5-10 – Appendix A), the compass is introduced as an explorer of a magnetic propriety of the space in one point that had to be explored and defined. In particular, the interaction between magnets are explored observing the rotations induced by the magnetic interaction and the analogy between the behaviors of the hanging magnet and the compass.

Even if the role of the representations was inserted already in a marginal way in the first ten steps of the learning path, in the eleventh it became crucial and is strictly related to the development of the formal representation of the physical entities involved (activity 11 – Appendix A). In particular in Activity 11.c, the students provide spontaneously a first representation of the magnetic properties of the space in one point. Their early representations are in all of the cases categorizable as a pictorial or a stylized representation of the compass needle representing or not the orientation of the needle. These will be the ground on which construct the vectorial nature of the magnetic field starting from this spontaneous versorial one.

But first, the representation by means field lines is presented to pupils overlapping the field lines representation to their versorial representation and discussing the validity and the pro and contra of both ones (Activity 11.d-12 – Appendix A).

In activity 13 was addressed in particular the limits of the versorial representation highlighting experimentally how this first formal representation is not able to describe all the characteristics of the magnetic field highlighting the need of introducing a way to represents also the intensity of this property. Highlighted an solved this issue of the versorial representation, the same problematic will be raised as concern the field line representation and in particular observing that in a simple field lines representation there is not a quantitative way to have information as concern the intensity of the magnetic field even if to try to correlate the distance (57%) or the density (29%) of the line with the intensity of the field – the idea that the intensity of the magnetic field is constant along a line was proposed only by few students (3%).

Following this shared expected spontaneous (and not correct) prevision, during activity 16, pupils are encouraged to validate their prevision and measure the value of the flux of the magnetic field between two field lines relating it to the height of the stripes bounded by the two lines. Then, looking that this correlation does not fit directly, after a discussion on the tridimensional structure of the magnetic field, they re-do the experiment looking for a correlation between the intensity of the magnetic field in one point and the area of the section of the tube constructed on the stripe bounded by the line in this point.

What emerge from this exploration is that there is an inverse proportionality between the value of the intensity of the magnetic field and the section of the tube. It means that the product between these two quantity had a constant value for each tube, but the value of this constant varies from tube to tube. It means that exist one way to relate the intensity with the section (and then the height) of a tube with the intensity, but the factor of correlation is not the same for all the tubes.
In this so is necessary a renormalization of the line to have the same value of the constant for each tube and so connecting equal height of the tube to equal intensity of the magnetic field.

In this way is possible to insert in the field line representation a metric that allow students to do quantitative forecast on the structure of the field around the magnet and in the same time, being the constant along the tube, the flux of the magnetic field, it is possible to correlate quantitatively the number of tubes crossing a surface to the flux of the magnetic field through a surface or a circuit.

Then the learning path proceed with the explorations and analysis of different sources of magnetic field (Activities 17 and 18) and the exploration of the Lorentz force (Activity 19). At least, the phenomena of the electromagnetic induction is presented as an experimental exploration in which students had first to freely explore qualitatively the phenomenology individuating the main parameter that had a role in it (Activity 20) and then study the phenomena in an explorative way (Activities 21 and 22).

**Data and findings**

Data were collected from the students’ writings on the inquired based personal worksheets proposed and from the audio recording of the argumentative discussions. Here will be reported and discussed only the data concerning the particular steps of the learning path that are related to the research questions took into account in the introduction.

For each question the students answers are categorized and grouped in categories taken in accordance with the main categories highlighted in literature for analogues questions and in new categories that emerged from the grouping of the data in the framework of a phenomenographic analysis of the students’ answers. In particular as concern the early phase of exploration the spectra of the possible answer is quite spread and different from class to class.

For instance in the following graph (Figure 1) are represented the distribution of the earlier representation used by the students in Activity 11 to represents the property of the magnetic property of the space.

Looking at the results of the MF and the TV classes (a classical lyceum and a scientific lyceum respectively), the distribution of the data are manifestly different and they overlap only on few mainly minority categories. In particular the MF students seems to use spontaneously more formal terms related to their scientific instruction, while the TV students proposed more often iconography representations of the needle.

**Figure 1.** Distribution of the earlier representation used by the students in Activity 11
This also persist after the performing of the activity 13 in which, even if almost all the students recognize the necessity to use a vector as formal entity, the justification that arise from the discussion is quite different between the two classes (Figure 2).

Figure 2. Argumentation concerning the need of using a vector as a formal entity

All the TV students argue referring to the different properties that had to be represented, while the majority of the MF students goes beyond this first level of argumentation expressing it in terms of the principle of superposition.

As concern instead the prevision of the way in which students proposed to extract the information from the draw of the field lines as concern the intensity of the magnetic field in each point of the paper, the distribution of the answers is almost the same in the all classes and could be summarized as in Figure 3.

Figure 3. Distribution of the intuitive students’ proposals to extract from the field lines representation, information concerning the intensity of the magnetic

How could be seen from data, the idea to correlate the distance and/or the density of lines with the intensity of the magnetic field is spread among the students and, even if it is not the right interpretation, it the usual angle of attach propose by the students to solve this issue related to the introduction of a metric in the field lines representation. In fact, after the performing of the Activity 16, the 84% of the students (categories A and B reported in Figure 4) explicit a correct statement for the definition of a two-way relation between the lines distance and the intensity of the magnetic field in one point and then, during the big group discussion, the proposal of reshaping of the pattern of lines in a way that ensure all tubes have all the same value of the product between the intensity of the field in one point and the section of the tubes (or the square of the height of the stripes) emerges in all of the groups.
Figure 4. Students conclusions after the Activity 16 concerning the ways in which relate the intensity of the magnetic field and the property of the field lines representation.

To investigate when the magnetic field becomes a referent for the students, the analysis was focused on students’ replies and argumentation to Activities 20 and 21.

During the qualitative exploration of the electromagnetic induction, all the groups of students performed at least one way to produce the phenomena and explored the variables involved in the phenomena. Figure 5 gives an overlook of which were the observation done by the groups (in this case the category used in the reporting of the data are not mutually exclusive because each groups could provide more than one observation.

Figure 5. Observation done by the students during Activity 20 as concern the ways in which generate (or not) electromagnetic induction and the individuation of the variables involved.
In addition, as concern the methodological aspect adopted by the students during the experimental exploration proposed, several groups perform a double check (they lowered and then raised the value of a parameters) denoting so a need of rigor and formality and highlighting also the need to construct, even in the qualitative case, a formalization of the correlation between the factors and the variables involved and several of them 71% use the flux of the magnetic field as a conceptual referents which its rate of variation among time produced the induced current. Looking at Figure 6, where are reported the replies to questions 20.3, there is also a 25% who refer to the lines without do manifestly references to the concept of flux.

<table>
<thead>
<tr>
<th></th>
<th>There is generation of current when there is a change in the flux of the magnetic field gone through the circuit (71%)</th>
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<tr>
<td>II</td>
<td>The current produced is proportional to the speed of the field lines variation through the coils, the number of windings and the radius of the coils (25%)</td>
</tr>
<tr>
<td>III</td>
<td>NR (4%)</td>
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**Figure 6.** General interpretation provided by students at the end of the qualitative exploration of the electromagnetic induction.

During the quantitative exploration, a minority of the students speaks in terms of field line and flux (36%), while the main part (63%) spontaneously correlate the physical situation with the phase of the graph in relation with the position and the movement of the magnet. As emerged in the class discussion, this trend were due to the difficult that the students has to see the movement of the field lines representation with the magnet.

**Discussion and conclusions**

By means of this experimentation is shown how an experimental exploration of the properties of a physical entity done in a prospective of gradual construction of the formal properties and allow student to construct the meaning of abstract entities giving physical meaning of their representation. In this way, the formal entity becomes a conceptual referent having a meaningful graphical representation that allow students to do prevision and provide interpretation of the explored phenomena. In particular the magnetic field became the main conceptual referent in situations in which the source of the magnetic properties is at rest, while some difficult persist when the sources are in motion. The role of the experimental exploration for the investigation of the induction phenomena as they were proposed have a double value: in the qualitative exploration students found and construct an explanatory model based on the abstract entity that they had characterized earlier; in the quantitative one, students overcome the limits in which the formal entity were experimentally formalized to provide a new parameters in the description of the field relating the movement of the lines with the source of the magnetic properties. So there is a double value of the experiment: validation and extension of the model.
Appendix A

Summary of the learning path and the inquired based learning path proposed.
References


Nonlinear Optical Second Harmonic Generation as an Advanced Undergraduate Experiment

Ivan S. Ruddock, Nonlinear Spectroscopy and Sensing, Department of Physics, University of Strathclyde, Glasgow, United Kingdom

Abstract

The generation of the second harmonic at 316.4 nm of 632.8 nm light from a He-Ne laser is described as the basis of an advanced undergraduate experiment. Activities include the study of the dependence of the conversion efficiency on phase-matching angle and the intensity of the incident laser beam. The experimental exercises are reinforced by theoretical analysis of beam propagation within the nonlinear crystal using a ray tracing matrix approach.

Introduction

Second harmonic generation (SHG) is the archetypal nonlinear optical phenomenon and occurs when a laser beam, incident on certain transparent crystals, is converted into another beam of double the frequency or half the wavelength. There are many other nonlinear optical processes including sum and difference frequency generation, higher order harmonic generation, four wave mixing and optical phase conjugation, the optical Kerr effect, stimulated Brillouin and Raman scattering, but second harmonic generation was the first to be demonstrated soon after the invention of the laser in 1960 [Franken et al (1961)]. It is also commercially important with frequency doubled infra-red lasers such as Nd:YAG being the usual sources of powerful visible light, both continuous wave and pulsed. The design and operation of a wide range of existing and potential optical devices can also be understood in terms of the concepts of nonlinear optics including the optical parametric oscillator and white light continuum generation in optical fibres. Second harmonic generation makes an ideal experiment for an advanced undergraduate physics laboratory because it contains within it the important elements of nonlinear optics, i.e. the nonlinear dependence of the generated intensity on the incident laser’s intensity, and the need for phase-matching in which the incident and generated beams travel with the same phase velocity. Unfortunately, illustrative examples are rarely found in undergraduate laboratories on account of the misplaced assumptions that the necessary equipment is expensive and that a high power laser is required along with the attendant safety concerns. Surprisingly, second harmonic generation can easily be performed with milliwatt power He-Ne lasers or equivalent, and home-grown crystals. In the University of Strathclyde’s Department of Physics, the apparatus is provided in triplicate in recognition of its status as a core topic that all students should perform.

In this paper, second harmonic generation as performed in an undergraduate teaching laboratory is described and typical results presented to show its relevance to lectures in optics, laser physics and instrumentation. The topics covered are (a) the dependence of the second harmonic power (at 316.4 nm) on the fundamental power (at 632.8 nm) as a demonstration of the nonlinearity of the phenomenon, (b) the dependence of the second harmonic power on the laser’s propagation direction in the crystal in the vicinity of the phasematching direction as an exercise in birefringence and refraction, and (c) the dependence of the second harmonic power on the laser beam’s spot size in the crystal as an exercise in Gaussian beam optics. In performing the experiment, students also gain experience in using lasers, photomultipliers, optical filters, oscilloscopes and amplifiers.

Background and Theory

The theoretical framework of SHG has been discussed extensively in the literature during the past fifty years and comprehensive surveys of the topic may now be found in most student textbooks on laser physics, modern optics and quantum or optoelectronics [Guenther (1990), Yariv (1985), Gatak & Thyagarajan (1989)]; consequently only a resume of the basics of the subject will be given here.
Nonlinear Polarisation

The second harmonic of a light wave of frequency $\omega$ is produced by a crystal if the induced electric polarisation has a component oscillating at $2\omega$. This happens when the polarisation is a nonlinear function of the electric field as will occur at or near the focus of a laser beam focused inside the crystal. The relationship between polarization and electric field can be represented by a polynomial of the form:

$$P = \varepsilon_0 \chi_1 E + \varepsilon_0 \chi_2 E^2 + \varepsilon_0 \chi_3 E^3 + \ldots$$  \(1\)

where $\chi_1, \chi_2, \chi_3, \ldots$ are the first, second, third, and higher-order electric susceptibilities of the medium. The frequencies of the terms in the expression for the polarization, $P$, are the original frequency, $\omega$, and the higher frequencies $2\omega, 3\omega, \ldots$ giving rise to harmonics of the original frequency $\omega$. Because $\chi_2, \chi_3, \ldots$ are small compared with $\chi_1$, nonlinear optical effects were not observed until after the invention of the laser in 1960. The expression linking the generated second harmonic intensity, $I_2$, with that of the incident laser beam, $I_1$, and the length of the crystal, $l$, etc., is

$$I_2 = \frac{\mu_0}{\varepsilon_0} \frac{\omega_2^2 \chi_2^2 I_1^2}{2c^2 n_2^2 n_2^2} \left[ \frac{\sin(\Delta k l/2)}{\Delta k l/2} \right]^2$$  \(2\)

It is derived by first using the wave equation to obtain $\partial E_2/\partial z$ where $E_2$ is the amplitude of the second harmonic wave, and then integrating it along the propagation path $z$; subscripts 1 and 2 refer to the incident and second harmonic waves respectively, $c$ is the speed of light, $n$ is the refractive index of the crystal, and $\Delta k = k_2 - 2k_1$, the phase mismatch with $k$ the wavenumber. Only media which lack inversion symmetry, for example anisotropic crystals, possess non-zero $\chi_2$. That this is so can be seen by inspection of equation (1) since in a centrosymmetric crystal, reversal of the electric field must leave the magnitude of the polarisation unchanged. A consequence of a crystal being anisotropic is that it exhibits birefringence, but this in turn can be exploited to produce “phasematching” resulting in the efficient generation of the nonlinear signal.

Phasematching

If $\Delta k \neq 0$, as is normally the case due to dispersion, then the average second harmonic intensity is proportional to $\sin^2(\Delta k l/2)$ and it oscillates with distance through the crystal. The second harmonic waves generated at different points along the beam’s path do not reinforce each other but interfere since they are not travelling at the same speed as the incident wave. If however, $\Delta k = 0$, then $I_2 \propto l^2$ giving quadratic growth of the second harmonic intensity with distance. Phasematching is said to occur under these conditions as the refractive indices and phase speeds at the incident and second harmonic frequencies are equal. Figure 1 shows the dispersion curves of the negatively uniaxial crystal used in this experiment, Ammonium Dihydrogen Phosphate (ADP). It is clear that there exists in this crystal a direction $\theta$ relative to the optic axis in which the ordinary index at the incident wavelength $\lambda_1$ is equal to the extraordinary at $\lambda_2$. The opposite scheme applies in a positive uniaxial crystal although both cases are referred to as Type 1 phasematching. Type 2 occurs when incident ordinary and extraordinary photons combine to produce the second harmonic.

Figure 1. The wavelength dependence of refractive index for a negatively uniaxial crystal such as ADP. At an angle $\theta$ to the optic axis, the ordinary index at the incident wavelength $\lambda_1$ is equal to the extraordinary at the second harmonic wavelength $\lambda_2$.
Experimental Arrangement

The basic set-up required for the observation of SHG by a 632.8 nm He-Ne laser is shown schematically in Figure 2. The plane polarized 2 mW laser beam is focused by a x10 microscope objective or equivalent into an ADP crystal positioned on a calibrated turntable such as found in a laboratory spectroscope. The lens is in a simple mount that allows the focus of the laser beam to be tracked smoothly through the crystal with its longitudinal position measurable to a precision of 5 ?m by means of a standard engineer’s dial gauge indicator. The UV light generated is detected by a photomultiplier tube such as a Hamamatsu IP28 through a Schott Glass UG11 filter to block the red laser light. A red filter, preferably a 632.8 nm interference filter, is also necessary to reject the intense blue light transmitted by the front mirror of the laser which would otherwise swamp the second harmonic. The signal is sufficiently strong to be observed on an oscilloscope but a simple chopper is a useful aid during initial adjustment and for helping with quantitative measurements. If available, a lock-in amplifier or gated integrator is a desirable addition.

![Image of experimental setup]

**Figure 2.** Experimental arrangement for generating and detecting second harmonic.

The entire experiment is assembled on a single triangular optical bench using simple saddles and components. The ADP crystals used here are 2.15 mm and 0.36mm in thickness and are cut approximately for Type 1 phase-matching of 632.8 nm at normal incidence. Since ADP is negatively uniaxial, the crystal and laser must be orientated relative to each other such that the light is always incident in the ordinary polarization plane while the crystal is being rotated; this is accomplished by rotating the crystal about an axis parallel to the plane of polarization of the laser beam but perpendicular to the plane containing the crystal’s optic axis (see Figure 2). If suitable nonlinear crystals are not available, samples of urea may be easily grown and used straightaway without polishing. In this case, at room temperature and at a wavelength of 632.8 nm, the phasematching scheme is Type 2 [Dunn & Akerboom (1985)].

Experiments

SHG is immediately apparent if the laser is focused on the crystal, while it is being adjusted and the photomultiplier output is being monitored. If for any reason the phenomenon is difficult to observe, and a lock-in amplifier is being employed, then by removing the red filter, the chopped blue emission from the laser discharge provides a test signal for the phase of the detection system to be set.

Phasematching Angle

Intense second harmonic is only generated when the fundamental and second harmonic waves are travelling at the same phase speed within the crystal. As outlined above, this can be arranged by exploiting the birefringence of the crystal to find a direction in which the refractive indices are the same.
Figure 3. Dependence of the second harmonic signal on (a) the incident beam’s angle of incidence on the crystal and (b) the incident beam’s angle of refraction for an ADP crystal of thickness 0.36 mm. The angles of incidence and refraction are related by Snell’s law evaluated using the ordinary refractive index at 632.8 nm.

Data points (a) in Figure 3 show the variation in second harmonic power with angle of incidence for the thin crystal. Depending on the accuracy of the cut of a crystal, the angle of incidence may be quite small; ideally it should be zero. The angular tolerance for a particular set-up is more properly demonstrated by converting the measured angles of incidence to the corresponding angles of refraction by Snell’s law with the refractive index of the crystal at 632.8 nm being obtained using the Sellmeier equation [Kirby & DeShazer (1987)]. Data points (b) show the second harmonic power as a function of internal angle which as expected is narrower than that of the external, due solely to refraction. The residual width of the peak is a measure of the laser beam’s convergence and divergence as it passes through the crystal.

Intensity Dependence

Laser power. Since SHG is mediated by the second order component, $\chi^{(2)}$, in the expansion of the susceptibility, the second harmonic intensity generated is proportional to the square of the fundamental intensity. If the incident beam’s cross-sectional area is kept constant, then the signal is proportional to the square of the laser power. Although laboratory He-Ne lasers are normally of fixed power, they can be controlled by neutral density (ND) filters. With NDs of 0.1, 0.2, 0.4 and 1.0 used singly and in combination, transmissions of 0.80, 0.63, 0.50, 0.40, 0.32, 0.25, 0.20 and 0.10 can be selected to conveniently adjust the laser power incident on the crystal. The second harmonic power as a function of the incident laser power is shown in a logarithmic plot in Figure 4. As expected, most of the points lie on a line of gradient 2.
Figure 4. A logarithmic plot of the dependence of the second harmonic signal on the fundamental power. Most points lie on a line of gradient 2 confirming the quadratic nature of process.

**Beam cross-sectional area.** The intensity dependence can also be demonstrated by varying the area of the focused laser spot. This is achieved by moving the lens relative to the crystal. The subsequent analysis uses the propagation equations for Gaussian beams, theory normally covered in a Laser Physics lecture course but not often applied in an undergraduate laboratory. Typical results for when the lens is moved by ±2.5 mm either side of the position of maximum second harmonic signal are shown in Figure 5, data points (a) and (b) for the thick and thin crystals respectively. The dramatic increase in the conversion efficiency as the tightest focus passes through the crystal is clearly illustrated.

Figure 5. Dependence of the second harmonic signal on the position of the crystal relative to the focus of the lens at \( z = 0 \) for crystals of thickness (a) 2.16 mm and (b) 0.36 mm. The solid curve is \( w(z)^{-2} \) evaluated using only the measured parameters of the experiment.
From (2), the second harmonic intensity, $I_2$, is proportional to the square of the fundamental intensity, $I_1$. Now, if the laser spot in the crystal is approximated to be a disc of radius $w(z)$ of uniform intensity, then $I_2$ is clearly proportional to $w(z)^{-4}$. However, $I_2$ is the intensity of the second harmonic beam as it exits the crystal and not at the aperture of the photomultiplier. As long as this dimension is greater than the diameter of the second harmonic beam, the quantity detected is the spatially integrated second harmonic intensity, i.e. the second harmonic power, $P_2$. At the crystal, the two quantities are related by $P_2 = I_2 \times \pi w(z)^2$ and hence the detected second harmonic signal is proportional to $w(z)^{-2}$ for constant laser power.

Figure 6. Schematic view of the beam diverging from the aperture of the laser and being focused to a beam waist of spot diameter $2w_0$. At a distance $z$ from the focus, the beam spot diameter is $2w(z)$, and $2w_1$, $2w_2$ and $2w_3$ $(= 2w_2)$ are the spot diameters at the laser and input and output planes of the lens respectively.

In Figure 6, the Gaussian beam is shown expanding from the output of the laser and being focused by a lens of focal length $f$ to a spot of radius $w_0$. The beam spot radius, $w(z)$, a distance $z$ symmetrically on either side of the focus given by

$$w(z) = w_0 \left[1 + \left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]^{1/2}$$

(3)

The spot radius "$w$" denotes the $1/e$ radius of the electric field distribution and the $1/e^2$ radius of the light intensity in the cross-section of a fundamental mode Gaussian beam. The size of the light spot at the focus, $w_0$, is determined by the focal length of the lens and the spot radius, $w_0$, of the light incident on it. By application of the ABCD ray tracing matrices [Guenther (1990)] for the lens and the displacement between it and the focal point, $w_0$ may be shown to be

$$w_0 = \frac{\lambda f}{\pi w_2} \left[1 + \left(\frac{\lambda f}{\pi w_2^2}\right)^2\right]^{-1/2} \approx \frac{\lambda f}{\pi w_2}$$

(4)

with the approximation relevant to the dimensions encountered in most practical situations.

The laser used in this experiment has a quoted $1/e^2$ beam radius ($w_1$) of 0.295 nm. Application of (3) yields a spot radius of 0.505 mm ($w_2$) at the input of the lens when it is 60cm from the laser. The x10 objective has an equivalent focal length of 16 mm which results in a focus of spot radius ($w_3$) of 6.39 μm using (4). Thus the variation in the spot radius on either side of the focus, $w(z)$, is given by (3) to be

$$w(z) = 6.39 \mu m \left[1 + 24.3 \left(\frac{z}{\mu m}\right)^2\right]^{1/2}$$

(5)
To fit theoretical curves to the experimental points in Figure 5, $w(z)$ is evaluated using (5) over the same range of lens adjustment. The agreement of the computed points is exceptionally good for the thin sample but poor for the thick one. This is because the model assumed that the second harmonic was only generated in an infinitesimally thin slice of crystal. In practice, the conversion efficiency is high provided the focus is still located within the crystal and so for the thick crystal, the curve is effectively a measure of its thickness, ~ 2 mm. When the sample is thin, the variation in spot radius through it is negligible and hence the simple model applies.

Discussion and conclusions

An undergraduate experiment featuring the phenomenon of second harmonic generation of a laser has been described. The experiment illustrates the basic principles of the process, phasematching and power dependence. In addition, it includes an exercise requiring the application of Gaussian beam optics and illustrates well the calculations which a graduate physicist working in this field would be expected to be able to perform.

References


The Effects of Autonomous Choice on Students’ Interest and Enjoyment in Learning Physics

Nicholas Hall, Department of Physics, University of California, Davis, CA 95616, USA
David Webb, Department of Physics, University of California, Davis, CA 95616, USA

Abstract

The role of autonomy in students’ interest and enjoyment in learning physics was investigated from a Self-determination Theory perspective. Self-determination Theory holds that autonomy is a basic human need of central importance to student motivation and performance, so an understanding of the effects of student autonomy on the student experience has implications for course design. A controlled experiment investigated the effects, on student interest and enjoyment in learning physics, of the number of opportunities for autonomous choice provided students. The controlled experiment compared two sets of classes in a large-enrollment undergraduate introductory physics course. Students in the control group spent each class working through a required series of activities. Students in the experimental group worked through required activities during approximately the first half of each class. During the rest of each class, however, students in the experimental group were free to choose what to work on. It was found that the increased opportunities for autonomous choice in the experimental group led to significant gender differences in interest and enjoyment in learning physics, with women’s interest and enjoyment becoming lower than men’s. These gender differences in interest and enjoyment could not be accounted for by differences in performance or perceived competence.

Introduction

Autonomy refers to the ability to act of one’s own volition or free will without outside pressures or influences. In this study we investigated the role of autonomy in students’ interest and enjoyment in learning physics in an undergraduate introductory physics course. Specifically, we investigated the effect, on student interest and enjoyment, of the number of autonomous choices provided students during class. The study was performed to better understand how in-class activities could be designed to maximize student interest and enjoyment. This study thus has implications for introductory physics course designers. Efforts to enhance students’ interest and enjoyment in learning physics may also be beneficial to increasing the number of students obtaining bachelor’s degrees in physics in the United States, which remains relatively small compared to the other natural sciences (see, e.g., National Science Board [NSB], 2012, Table 2-18).

Self-determination Theory (SDT; Deci & Ryan, 1985; Deci & Ryan, 2000; Ryan & Deci, 2000b) defines two types of human motivation, intrinsic motivation and extrinsic motivation. When intrinsically motivated, an individual does something because it is inherently interesting or enjoyable (e.g., fun or challenging). Intrinsic motivation is the most autonomous form of motivation. When extrinsically motivated an individual does something because it leads to an outcome separate from the activity itself (Ryan & Deci, 2000a). Extrinsic motivations for engaging in an activity can vary in the degree to which they are autonomous versus controlled (Deci & Ryan, 1985). For example, an individual engaging in an activity solely to receive praise or avoid punishment has a highly controlled form of extrinsic motivation. An individual engaging in an activity as a step toward a goal that has value for that individual would be a more autonomous form of extrinsic motivation.

SDT comprises several mini-theories, including Cognitive Evaluation Theory (CET; Deci & Ryan, 1985). CET holds that an individual must have the basic needs for autonomy and competence satisfied in order for their intrinsic motivation for engaging in an activity to persist. The need for autonomy refers to the desire to act volitionally (i.e., be self-determined). The need for competence refers to the desire to act effectively (White, 1959). Satisfaction of the needs for autonomy and competence is also key for an individual’s extrinsic motivation for engaging an activity to become more autonomous (i.e., more because they want to) and less controlled (i.e., less because they feel they have to). In summary, Self-determination Theory holds that autonomy and competence are intrinsic and universal needs that are essential for the psychological health and optimal functioning of an individual (Deci & Ryan, 2000). This work focuses on efforts to satisfy students’ need for autonomy.
Various correlational (e.g., see Black & Deci, 2000 with undergraduate students; Reeve, 2002 for a review) and experimental (e.g., see Reeve, Jang, Carrell, Barch, & Jeon, 2004 with high school students; Su & Reeve, 2011 for a meta-analysis) studies have investigated the degree to which instructors are supportive of student autonomy in their interactions with students and the resulting effects on various aspects of the student experience. In addition, we have shown (Hall & Webb, 2013, hereafter Paper I) that students who perceived their instructors as more autonomy supportive tended to become more interested in learning physics, become less anxious about taking physics, come to study physics for more autonomous reasons, and perform better (for a subset of students). The current paper extends this previous work by considering the effects of a course design that specifically provided introductory undergraduate physics students with opportunities for autonomous choice as to how to spend their time, independent of the instructor.

The Course

This study was performed during Winter Quarter 2010-2011 in an undergraduate introductory physics course at the University of California, Davis primarily for students majoring in the biological sciences. This course is known as Collaborative Learning through Active Sense-making in Physics (CLASP; Potter et al., 2012). It is a three quarter series with course numbers Physics 7A, 7B and 7C. This study was performed with the approximately 300 students in Physics 7A. The students were divided into two lecture sections that met weekly for 80 minutes and were taught by a single course lecturer. Students were also divided into approximately 30-student discussion/lab (DL) sections that met twice a week for 140 minutes each time and were taught by graduate student instructors. In a typical CLASP course, students spend most of their DL time working in groups of four to six students at a group chalkboard. Group work is interspersed with student presentations and brief whole class discussions facilitated by the DL instructor.

The Experiment

We designed a controlled experiment to address the research question of whether the number of autonomous choices provided students would affect students’ interest/enjoyment in learning physics. The experiment increased the number of autonomous choices provided students in 6 of the 11 DL sections by adjusting the curriculum (mostly by removing parts of activities) so the second half of each DL was open to the students to choose how to apply, expound on, or clarify what they had learned. During the second half of each class students were provided with options (e.g., working on removed activities, additional supplementary problems, etc.), but were not required to choose from these and were encouraged to apply the concepts of the course in ways of interest to them. We compared these DLs with more autonomous choice (hereafter ACDLs) to a control group of five standard DLs (hereafter SDLs) in which students worked on the required activities during the whole DL. The activities removed from the ACDLs were carefully chosen by the lecturer and authors so that the ACDLs and SDLs covered the same main concepts. Thus students in SDLs had in-class applications of concepts chosen for them, whereas students in ACDLs were free to make their own choices as to how to apply the concepts. We made various measurements with surveys discussed below in both the experimental (ACDLs) and control group (SDLs) and investigated the effects of autonomous choices by comparing the two groups.

Methods

In this section we first discuss the selection of the study population and then the measures used in this work. 313 students received a final grade in the course. We excluded 2 students who did not take the final exam. The students registered for the course without any knowledge of how the sections would be taught and each section was completely full so students could not easily change sections. For these reasons, we consider the division of students into sections to be almost random. Five of the DL instructors taught two DL sections. To control for instructor effects, these five instructors taught one SDL and one ACDL. The students of the instructor who taught only one section were not included in the study. Additionally, one of the DL instructors chose to teach his/her two sections in a way quite different from the SDLs or ACDLs, thus his/her students were excluded from the study. Of the 233 remaining students, only the 165 students who responded to all items on our surveys were included in the study. The participants consisted of 100 women and 65 men. This study population is identical to that of Paper I with the exception that Paper I included the students of the instructor who taught only one section (Instructor 1 in Paper I).
Instructors were asked in their ACDLs to have students spend the first 70 minutes working on the abbreviated activities and the second 70 minutes working on things of the students’ choosing. The instructors were also asked to run their ACDLs as they do their SDLs: have students work in groups of 2-6 if they were working on the same thing, encourage students to work at the board, and have students present their work during the 2nd half (to help ensure that students worked during the 2nd half). Additionally, the ACDL instructors were asked to require that their students work on DL-related content only and not the upcoming homework. To measure fidelity of implementation, instructors filled out an ACDL Report after each ACDL providing information such as how much time students spent working on the 2nd half options, what students chose to do during the 2nd half, etc.

**Measures**

Questionnaires were administered to students by the authors (DL instructors were not involved) during the first week of instruction (hereafter, T1) and/or during the last (10th) week of instruction before the final exam (hereafter, T2). Students were informed that responding was voluntary and had no effect on their grade. They were informed that their responses would be kept confidential and specifically not shared with their instructors.

**Interest/Enjoyment Measure:** This measure adapted by Black & Deci (2000) from Williams & Deci (1996) has nine items and attempts to measure students’ interest and enjoyment in learning introductory physics. The students rated the truth of each item on a five-point scale and our Interest/Enjoyment measure is the sum of the nine items. This survey was administered at T1 and T2.

**Perceived Competence Measure:** This measure was adapted by Black & Deci (2000) from Williams & Deci (1996). It has five items and attempts to measure how competent students believe they are at learning introductory physics. The students rated the truth of each item on a five-point scale. Our Perceived Competence measure is the sum of the five items. This survey was administered at T1 and T2.

**Learning Climate Questionnaire (LCQ):** This measure was adapted by Williams & Deci (1996) from the Health-Care Climate Questionnaire of Williams, Grow, Freedman, Ryan, and Deci (1996). This questionnaire attempts to measure how autonomy supportive (vs. controlling) students perceive their DL instructors to be. Students rated their agreement/disagreement with each item on a seven-point Likert-type scale. The first item of this survey was the only item for which students in the experimental group had significantly different responses on average from students in the control group \[t(163)=3.7, p<0.001\]. This was expected given that the first item of this survey attempts to measure the number of choices the instructor provides students, which happened more in the experimental group by design. This survey was used to control for the correlation of Instructor Autonomy Support (IAS) with Interest/Enjoyment (see Paper I) in investigating the effects of the number of choices provided students on Interest/Enjoyment. As we certainly do not want to control for the number of choices when trying to measure the effect of the number of choices, the first item of this survey was not included in this study. The sum of the remaining 14 items is our IAS measure. This survey was only administered at T2, after students became familiar with their instructors’ teaching styles.

**Performance:** Students’ final course grades were composed of eight weekly quizzes given in lecture as well as a comprehensive final exam. Questionnaires were administered at T2, which was after the eight quizzes and before the final exam.

**Data and Findings**

We used Stata statistical software to perform our analysis. t-tests were two-sided. They also did not assume the two distributions being compared had the same variance, thus Satterthwaite’s degrees of freedom (Satterthwaite, 1946) were reported. We also performed our multiple linear regressions with robust standard errors, which does not assume homoscedasticity of the residuals.

We considered the effects, on students’ interest and enjoyment in learning physics, of the number of autonomous choices provided students by comparing student Interest/Enjoyment in ACDLs and SDLs. To isolate the effects of the course design on Interest/Enjoyment we must first control Interest/Enjoyment at T2 [IE (T2)] for incoming Interest/Enjoyment [IE (T1)], thus creating a change score. We must also control for the effects of Instructor Autonomy Support on IE (T2) shown in Paper I. The residual of the following model is IE (T2) after controlling for these two effects:

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Below we simply refer to this residual as the change in Interest/Enjoyment (over the duration of the quarter). The change in Interest/Enjoyment was not significantly different between SDLs and ACDLs for all students combined [two-sided $t(140)=0.76$, $p=0.45$]. However, this result appears to mask a gender effect. We also looked at the women and men separately. The change in Interest/Enjoyment is plotted in Figure 1 separately for men (blue squares) and women (tan diamonds) and separately for SDLs and ACDLs. We found that the change in Interest/Enjoyment was similar for men and women in SDLs [two-sided $t(69)=0.6$, $p=0.5$]. By comparing ACDLs to SDLs we found that increased opportunities for autonomous choice led to a somewhat higher change in Interest/Enjoyment for men [two-sided $t(61)=1.6$, $p=0.12$] and somewhat lower change in Interest/Enjoyment for women [two-sided $t(84)=2.1$, $p=0.04$]. The different effects on men and women of increased opportunities for autonomous choice led to a highly significant difference between men and women in ACDLs in change in Interest/Enjoyment [two-sided $t(69)=3.9$, $p<0.001$]. The effect of increased opportunities for autonomous choice on change in Interest/Enjoyment can be measured by

$$x = (\text{Change in Interest/Enjoyment})_{\text{ACDLs}} - (\text{Change in Interest/Enjoyment})_{\text{SDLs}}.$$ 

We used Cohen’s $d$ to calculate the size of the effect of gender on $x$ as follows:

$$d_{\text{gender}} = \frac{x_{\text{men}} - x_{\text{women}}}{\sigma_{\text{pooled}}},$$

where the pooled standard deviation is that of the four distributions of change in Interest/Enjoyment that make up the numerator (from men and women in SDLs and ACDLs). Thus $d_{\text{gender}}$ measures the size of the effect of gender on changes in Interest/Enjoyment that resulted from increased opportunities for autonomous choice. We found an effect size of 0.83.

![Figure 1](image.png)

**Figure 1.** Change in Interest/Enjoyment over the duration of the quarter for men ($N=36$) and women ($N=53$) in Standard Discussion/Labs and for men ($N=29$) and women ($N=47$) in Discussion/Labs in which students were given more autonomous choice. The effects on Interest/Enjoyment of the degree to which students perceived their instructors as autonomy supportive have been controlled for. Error bars are 95% confidence intervals. $N=165$.

We investigated possible explanations of the different effects of autonomous choices on the change in Interest/Enjoyment of men and women. One possibility is that the differences in the change in Interest/Enjoyment seen in Figure 1 were a result of similar differences in performance. We thus add performance at T2 (i.e., Quizzes) as another control variable in the model as follows:

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\[ IE(T2) = B_0 + B_1 IE(T1) + B_2 IAS + B_2 Quizzes (T2). \]

We again calculated \( d_{\text{gender}} \) for the residual of this model and found an effect size of 0.85. Thus the gender effect could not be accounted for by differences in performance between men and women. Men did outperform women, however the difference in performance between men and women was similar in the SDLs and ACDLs and thus could not account for the different effects of autonomous choice on the change in Interest/Enjoyment of men and women.

A second possibility is that differences in perceived competence in learning physics accounted for differences in student interest and enjoyment in learning physics. To see if Perceived Competence at T2 would account for the observed gender effect we added it as a control variable in the model as follows:

\[ IE(T2) = B_0 + B_1 IE(T1) + B_2 IAS + B_2 \text{ Perceived Competence (T2)}. \]

We calculated \( d_{\text{gender}} \) again for the residual of this model and found a value of 0.83. Thus Perceived Competence (T2) did not account for the observed gender effect.

**Discussion and Conclusions**

We investigated how the number of autonomous choices provided to introductory physics students during class affected students’ Interest/Enjoyment in learning physics at the end of the quarter, after controlling for initial differences in Interest/Enjoyment. We also controlled for the effects of the degree to which instructors were supportive of student autonomy, which has been the focus of much previous work in this area. We found that the number of autonomous choices did not have a significant effect on the Interest/Enjoyment of all students combined, suggesting no average benefit or detriment in terms of Interest/Enjoyment to providing students with more autonomous choice. However, we also found that more opportunities for autonomous choice led to large differences between men and women in Interest/Enjoyment in learning physics (Cohen’s \( d = 0.83 \)), with women’s Interest/Enjoyment becoming lower than men’s. In other words, in terms of Interest/Enjoyment in learning physics, women responded significantly less favorably than men to having more opportunities for autonomous choice.

Paper I showed that Interest/Enjoyment was positively correlated with performance for students in this course. We thus considered whether the difference between men and women in Interest/Enjoyment as a result of increased opportunities for autonomous choice could be a result of similar differences in performance. We found that the observed gender effect remained after controlling for performance and thus could not be accounted for by differences in performance in the course.

Self-determination Theory holds that both the need for autonomy and the need for competence must be satisfied for an individual to remain intrinsically motivated to engage in an activity, i.e. to engage in the activity because it is interesting or enjoyable. While men and women in the ACDLs were given the same amount of autonomous choice, perhaps men and women had different levels of perceived competence that resulted in differences in Interest/Enjoyment. We controlled for our measure of perceived competence and found that the difference between men and women in Interest/Enjoyment as a result of increased opportunities for autonomous choice remained. Our measure of perceived competence assessed how competent students believed themselves to be at learning introductory physics and being successful in the course. It did not directly measure how competent students perceived themselves to be at engaging in the activities of the second half of each ACDL, including making one’s own choices regarding what to work on. Men and women may have had significantly different levels of perceived competence around these activities that resulted in differences in Interest/Enjoyment in learning physics.

Future work could survey students’ perceived competence in engaging in the activities specific to the second half of the ACDLs (making autonomous choices and working on the various things students chose to work on) and see if any existing differences between men and women account for differences in Interest/Enjoyment. Part of the autonomous choice given in the second half of the ACDLs was the ability to choose with whom to work (in other words, the ability to rearrange their workgroups). Perhaps the ability to make this choice had a significantly different effect on the Interest/Enjoyment of men and women. Future work could control for this by allowing students in the control and experimental groups to choose with whom to work throughout the quarter, thus narrowing the focus of the intervention. It would...
also be beneficial to track which students engage in which activities during the second half of the ACDLs to compare the choices of men and women. For example, perhaps men and women made the same choices on average but women's Interest/Enjoyment in these activities was lower than men's. Qualitative data such as classroom observations or interviews may also shed light on the observed gender effect.

In the context of the introductory physics course of this study, the number of autonomous choices provided students played an important role in differences between men and women in Interest/Enjoyment in learning physics, suggesting that great care needs to be taken in terms of the amount and type of autonomous choice provided students by the course design. The size of the observed difference between men and women in Interest/Enjoyment as a result of being given more opportunities for autonomous choice warrants further investigation, including tests of external validity.

References


The Need to Encourage FET Natural Science Teaching Profession Students at University to Study Physics as a Major

Itumeleng Barnard Phage, Natural Sciences Programme, School of Teacher Education, Central University of Technology - Free State, Bloemfontein, South Africa

Email address: iphage@cut.ac.za or phageh@gmail.com

Abstract

Students at tertiary level have not been up to scratch with Physics hence the poor or low number of Physics graduates in general. Universities are of course producing graduates in Natural Science including for the teaching profession but majority of them did not specialise in Physics. When we look at Further Education and Training (FET) or High School curriculum or syllabus, we find that Physical Science composed of Physics and Chemistry of equal weighting in final assessment is one of the subjects. Most teachers are comfortable with chemistry and as a result, Physics section suffers. Students at matric level end up not doing well in Physical Science and their results in it have been all time low. This has been a syndrome that has purported students not to be interested in careers in Physics including teaching. Most students at university will study Physics at First year level because it is a prerequisite for other majors or is compulsory at first. As a result, they end up doing it to pass it in order for them to be able to do their majors or just to pass it but not to have conceptual understanding and knowledge. This paper seeks to investigate possible ways by which if Physics is studied at university, the country will not be faced with a crisis of Physics teaching in schools. If this is done properly, students studying Physics careers will increase tremendously. Integrating both the methodology and content teaching and learning in Physics will enhance the pass rate in Science at high schools, which will be escalated in Science, Engineering and Technology studies at tertiary level or university. Science teachers in schools just need that motivation and confidence to teach the subject at ease. With this knowledge and skills in Physics imparted well at schools, the country will not be marginalised in terms of shortage of scarce skills careers.

Keywords: Specialise in Physics, Matric Physical Science, Science Teaching conceptual understanding and knowledge, integrate, methodology, scarce, skills, motivation, confidence, escalate, ease, high schools, curriculum, syllabus

Introduction

Physics is seen, as one of the core subjects required in most specialised field and skills like Engineering, Science, Technology, etc, but still there is a poor pass rate/performance at Further Education and Training (FET) School in Physical Science, which leads to a low number of graduates in Science. This has been evidenced from a low and poor pass rate in Mathematics and Physical Science in Matric. These subjects are the main requirement or entry subjects for learners to enrol in the fields of specialized skills.

Except that performance is poor and pass rate is low in these two core subjects, very few learners enrol for them in matric hence a very low number of learners who enter into tertiary education with them. This was also echoed by Professor Ruksana Osman, head of the Wits School of Education during the matric results release of early January 2011 that “One worrying trend, which has emerged over recent years, has been the declining number of students studying mathematics and physical sciences at matric level”

Physics is a major threat to learners and teachers in schools and cause of poor and or low pass rate in Physical Science, low number of enrolment in Physical at FET (High) Schools because of inability of School Principal to recruit qualified and trained teachers in Physical Science and Mathematics, especially under-privileged communities in rural and township schools. If a school can get a Science teacher, that teacher is likely to be uncomfortable to teach Physics sections or uncomfortable to perform experiments in both Chemistry and Physics. The reasons for these are mainly due to lack of proper training or lack of resources like a proper standing laboratory, unequipped laboratories to perform such experiments. Some schools
are struggling to sustain themselves since parents are able to pay school fees of their children, so they are also unable to acquire consumables required to perform most of the experiments. This has also been testified by most Principals and School Management Team members, members of School Governing Body (Parents Committee) and Department of Education Officials in poor communities who have consulted on this issue and affected schools.

Most learners, communities and schools in underprivileged communities and schools turn to regard subjects like Mathematics and Physical Science as difficult subjects. As a result, learners in school are streamlined to do these subjects, based on their early or previous academic merits from primary schools by their teachers and principal. Some schools select learners to do these subjects based on academic achievement of their sibling, relatives and or family. This has brought an on-going and current misconception in South Africa that if you are doing Physics or Mathematics you are very intelligent (clever) or you can do them because of your family background, i.e. you are a child of so and so, who is prominent and popular in the community about this and that. Those misconceptions are also subjective as they should not be of criminal nature. These indeed is a clear indicator that there is a need and it is paramount that tertiary institutions should produce competent and qualified Physical Science and Mathematics teachers, especially in Physics.

From this misconception, it means that in Mathematics and Physics unlike other subjects, one must have foundation for understanding the concept. In other subjects one can recap the content by just reading. There is a great offer outside teaching. For students with maths and physics teaching is the last option for them. Those with distinctions opt for Artisan, Technicians Engineers and medicine reasons:

- Poor salary
- Lack of resources like laboratory
- Teaching is not challenging for them

That is why our government must put measure in place to encourage learners study Mathematics and Physics.

To do this, our government has been concerned and implemented a strategy to increase the skills in Science, Technology, Engineering and Mathematics (STEM). In so doing and in order to retain skilled professionals, the government

- Established and introduced Dinaledi Schools
- Declared the teaching of these subjects in schools and the skills in the STEM field within the public sectors part of Occupational Specific Dispensation (OSD)
- Is offering bursary schemes to public to study towards teaching at tertiary level, namely, National Bursary schemes like Fundza Lushaka (meaning, “Teach the Nation”) and Provincial Education Bursaries
- Where necessary imported skilled labour outside the country to come and train as well as transfer those skills to its citizen

This one initiative from current government deliberations, as to whether to consider teaching mainly in STEM subjects as an essential service. It was and is still concerned that good Mathematics and Science teachers are leaving the education sectors to join the private and/ or industrial engineering and science sectors or are opting for senior management positions for remuneration purposes. The government has gone to the extent of re-hiring those retired teachers in STEM. Teachers in Mathematics and Science have been remunerated at a level of manager’s positions as part of OSD and part of their retention to continue teaching these subjects.

Because of shortage of teachers in schools in these subjects, government took an initiative to introduce Mathematics Literacy as basic Mathematics and to instil numeracy among learners and communities and so that teachers with little information or less qualified to teach Mathematics. Mathematics Literacy was not meant to replace Mathematics but was necessary for all learners irrespective of your field of study just basic maths. In so doing learners and community talents in skilled filled was exposed so that ultimately they could change to do

*WCPE 2012, Istanbul, Turkey*
Mathematics and Physical Science at early age. The other reason for introduction of Mathematics Literacy by government was to give learners and schools in disadvantaged communities the opportunity to get exposed to and conscious about subject required in the skilled fields. This would mean learners and communities would cope with in future with the economic and labour needs to sustain the country.

One more another aspect disturbing the government was the inability of teachers in FET Schools to teach Physics or Mathematics due to:

- Mathematics Literacy has replaced Mathematics hence inability to poor performance of in the Physics content
- More and more employment of foreigners to teach these subjects especially (language barrier and cultural differences), which means there is no skills transfer among its citizen (locals)

**Literature Study**

Students at universities can be motivated and encouraged to specialise in Physics if they have Mathematics knowledge and skill as the research awareness has denounced that Mathematics is the language or tool of Physics (Redish, 2005).

These students are unable to cope with the study of Physics and Mathematics and as a result there is a high dropout or failure rate in Physics at tertiary (university) level and there is a low number of Physics teaching graduates and this could be due to:

- Students lack the necessary mathematical skills needed to solve the physics problems.
- Students do not know how to apply and relate their mathematical skills in the context of physics.

As a results Mathematics has been seen to be a stumbling block in the study of Physics amongst not only high (FET) school learners but also among university students. This echoed by Pietrocola, M. (2008) when he said, “In physics teaching, mathematics is often considered responsible for scholastic failure. It is customary to hear from teachers that their students do not understand physics onaccount of their fragility in mathematical understanding. Many consider that a solid mathematical base in the years that precede physics teaching guarantees successful learning.”

Therefore, the question is, is the language used in Physics different and or difficult to the language used in Mathematics that it has becomes difficult to learn Physics without Mathematics skills. Pietrocola, M. (2008) uses Redish (2005)’s standpoint to emphasise this by saying that “…the language of mathematics we use in physics is not the same as the one taught by mathematicians. There are many notable differences” (page 1). Admitting that a many of the problems in physics teaching are found in commanding Mathematics reflects a naive epistemological positioning and ends up considering the latter an instrument of the former!

As a result, students specialising in Physics need to be developed and trained to acquire the necessary skill to apply the mathematical language in their Physics learning and studying. Physics and Mathematics lecturers will therefore have to apply these teaching and learning strategies in class so that students can be able to relate them in their study.

Another influence that can motivate students to specialise in Physics is the low number of quality Mathematics and Physical Science passes achieved by the class of 2011, which bodes ill and is a hindrance for government’s plans to create five million jobs by 2020 in the skills fields. Mathematics is a gateway subject to higher education, particularly in the more technical fields such as science and engineering (Mail & Guardian Newspaper, 10 JAN 2012 06:50 - FARANAAZ PARKER).

Therefore, if students are able to perform well in Mathematics at schools, they will be able to follow careers in technical that require and involve Physics as a subject. If students at universities are following career in teaching and specialising in Physics, they will be able to enhance the government’s plans to reach their target of creating five million jobs skilled included in 2020 within the country and among its citizens.
Building quality in the school system is about improving the knowledge judgment of teachers and the exam process is an important cog in this enterprise (NICK TAYLOR http://mg.co.za/article/2011-03-11-matric-quality-vs-quantity), so recruiting students to do and specialise in Physics at higher education, who will in turn pass their knowledge to learners in schools will greatly influence this quality.

The struggle by students in physics due its complexities and their inadequacies with skills and knowledge of Mathematics (Basson, 2002)

How an implicit epistemological curriculum can be analyzed, explicated and evaluated and how students’ intuitive epistemology plays a role in their learning (Reddish and Hammer, 2009)

Maimane, 2006 argued that motivation plays a role wherein learners, in these case university students, are actively involved in their learning and as a result students will clarify and develop learning concepts and skills. Recruitment of Physics graduates in teaching can also go the same route. Lecturers at higher education institution can adopt cognitive blending that also helps to deal with problems students encounter in the integration of mathematical and physical knowledge (Bing and Redish, 2007).

Physics students studying towards education degree can be trained according to two tenets of constructivism as defined by Roth, 2001 (1993), i.e., knowledge should be constructed instead of being transmitted from educator (Lecturer) to student and learning should applied as an adaptive process.

It is easy to memorise a simple recipe and repeat it – unfortunately, to acquire true understanding and knowledge you have to “learn to fish” (http://www.masterscience.co.za/science-news/extra-science-education-for-sa).

**Aims of study**

The researcher is a Physics lecturer to all undergraduate students in the School of Teacher Education, which is responsible for training and producing prospective and qualified teachers in different subject fields for Further Education and Training school. The department has a low number of students enrolled and specialising in Physics, hence producing low number of graduate teachers, not even enough to accommodate 5% qualified Physical Science in the neighbouring communities, not to mention at National level. The researcher is investigating as to why there is a need for students at Central University of Technology, Free State to pursue the career in Physics teaching and how to motivate them to do so.

**Problem statements**

The research is meant to investigate possible ways as to tow to transmit the relevant Physics knowledge and skills. This will help to equip, assist and support current and future prospective and qualified Physics teachers from Central University of Technology, Free State to teach this subject with confidence and enthusiasm in the schools.

In so doing, they will alleviate the current problem in Free State Province or South African schools as a whole the lack of not only Physical Science or Mathematics teachers but in Physics specifically, the source of why teachers cannot or do not want or unqualified to teach Physical Science.

**Research Questions**

The research is probing:

- The possible causes of high failure or poor pass rate in Physical Science due to Physics in FET (senior phase or high schools) schools, what influence does Physics part have in this?
- Factors causing Science teachers in schools not to teach Physics or what could motivate the Physics teacher at schools.
- Strategies to recruit and train Physics graduates to teach it at school.
- Methodology
Empirical Study:

Used a mixed method approach:

1. A standardized questionnaire similar to that of Beichner consisting of kinematic and linear function graphs was prepared by researchers and completed by 1st year Physics teacher students.

1.1 After students completed the questionnaire, students were given the opportunity to discuss their choice of answers and to support that, i.e., determine if and what Mathematics knowledge and skills help them to solve Physics problems.

2. Data was also collected from the Department of Education (DoE – SA) as:
   - to pass rate of Physical Science in Matric results
   - Comparison of the pass rate in the Physics paper (paper 1) and Chemistry paper (paper 2)

Results

Data 1

- 31 students completed the questionnaire
- Section A was composed of 13 Mathematics questions
- 69% of students passed section A
- 5% of Mathematics questions were left unanswered
- Section B was composed of 17 Kinematics questions
- 53% of students passed section B
- 30% of Physics questions were left unanswered
- 56% of students passed the overall questionnaire

Data 2

- The total number of candidates who wrote the exam dropped from 537 543 in 2010 to 496 090 2011
- 15% enrolled and wrote Physical Science
- Combined 46% enrolled for Mathematics and Mathematics Literacy
- The national pass rate for the class of 2011 was 70.2%, an increase of 2.4% over 2010.
- Overall 23% learners who enrolled for Physical Science passed it above 40% and no distinction.
In 2011, a total of 8,281 pupils (205 more than 2010), from 173 schools across the country wrote the IEB examination, boasting a 98.15% pass rate, only a slight drop compared to last year’s pass rate of 98.38%.

Despite the excellent pass rate, the IEB has been concerned by the steady decline in the number of pupils who take Physical Sciences in Grade 12—from 52.3% in 2008 to 47.4% in 2011.

The Combined Abitur-NSC qualification, offered by German schools in Cape Town, Johannesburg and Pretoria, consisting of five subjects assessed by the IEB and seven subjects assessed by the German education authorities, gives South African pupils recognition and entry at German universities. Out of 56 candidates, 55 gained entry to tertiary study in 2011. One learner achieved an exceptional performance.

The IEB is an independent assessment agency, separate from state and provincial examination boards, operating within the constraints of national legislation and provisions of the national quality assurance body, Umalusi.

**Conclusion and discussion of results**

**DATA 1**

- There is a clear indication that students do well in Mathematics in comparison with Physics.
- From classroom discussions of Physics teacher students the mathematics skills and knowledge that they require to solve and answer Physics problems.
- There were two things observed why students still passed Physics though not as good as they passed Mathematics:
  1. Most students used their prior and present knowledge in Physics to answer Physics questions than use Mathematical knowledge, i.e., minimal/unnoticed link/use between Mathematics and Physics concepts.
  2. Few students used their Mathematics knowledge and coupled it with Physics knowledge to answer Physics questions, e.g., use Mathematics linear graphs to interpret Physics Kinematics graphs.
- There is still a vast gap of comprehension of previous or prior knowledge to be applied/ transferred to new knowledge/learning.
- A large number of first year students still expect to be taught what they have learnt at high school in order to apply or use it in the new concepts they learn at university.

**DATA 2**

- Mathematics Literacy and Life Orientation subjects is the source of increased pass rate in matric examination, which is more of quantity than quality.
- Private schooling (IEB and Abitur-NSC) brings expected results – urban education.
- Farm schools and village schools (with high population) are at the receiving end of decline in matric, Mathematics and Physical Science enrolments and high failure rate, makeshift or no science teachers.
- They are followed by semi-urban (township school, depending also where township school is located) schools.
- Poor intention for students to enrol for teaching profession, i.e.: They are offered full free bursary to do teaching at university.
- They did not qualify or could not be admitted into engineering, science and other fields of study at university.
• Teaching is still regarded as a not status profession and does not pay like other fields studied in the same duration
• Private schools recruiting the best teachers and paying them well
• Lack of basic resources within poor communities
• Urbanisation is the ultimate choice for any qualified teacher
• Political interference in the governance of schools
• Lack of basic resources within poor communities
• Urbanisation is the ultimate choice for any qualified teacher
• Political interference in the governance of schools

Finally the “Top Five Reasons Why Teachers Teach (J. Ellen Fedder, http://voices.yahoo.com/top-five-reasons-why-teachers-teach-2602544.html)” are therefore not easily attainable with Physics teaching

Potential implications of findings

The research can lead to an increased realization by Physics teacher students as to what motivates them to be the Physics teachers and transmit and instill that interest to FET school learners to study Physics when they go into teaching

As such, more learners will be inspired and equipped to do and perform well in Physics and resulting in increased percentage pass rate in Physical Science in in matric, which would then mean high entry into university STEM studies, alleviation of lack OSD skills and poverty.

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Context-Based Physics Education and Learning With Newspaper Based and Other Authentic Learning Problems: An Empirical Study

Jochen Kuhn, University of Kaiserslautern (Ger)/Department of Physics/Didactics of Physics
Andreas Müller*, University of Geneva (CH) /Fac. of Science/Physics Dept. and Institute of Teacher Education
Patrik Vogt, Pädagogische Hochschule (University of Education) Schwäbisch Gmünd (Ger) Physics Education Group

* Corresponding author: Andreas.Mueller@unige.ch

Abstract

Context-based physics learning (CBPL) has a long-standing tradition and is considered as a highly promising approach in current physics education. Drawing on good practice and research evidence in physics (and other science) education, we investigated a specific form of CBPL, viz. learning with physics tasks and problems based on newspaper articles and the real-life contexts provided by them (newspaper story problems, NSP). This is an easy-to-have and flexible form of CBPL, and the goal of the study is to investigate its effects on both motivation and learning.

The quasi-experimental repeated measures design, instruments and validity controls will be presented, in particular instrument choice and development. Satisfactory values for Cohen kappa for interrater agreement on curricular validity of learning and test material (κC = 0.74 – 0.91), and for Cronbach alpha for reliability of all motivation and learning scales (αC = 0.74 – 0.89) were obtained throughout.

Results are presented for two topics (elementary kinematics, energy and energy conversion), based on a comparison (N = 911) of NSP treatment classes with control classes (with conventional exercises, but otherwise the same lesson plan, and the same teacher). The improvement of motivation is statistically significant, with practically large effect sizes (p < 0.05 in all cases; Cohen d up to 1.66). The same holds for learning (p < 0.05 in all cases, d = 0.9 and larger.)

Practical implications and possible limitations of these findings conclusion will be discussed, such as possibly small, narrow, and short term effects only (shown not to occur), and effects on higher order competences, such as critical thinking. In sum, we may conclude that newspaper story problems represent a promising, practitioner-friendly form of CBPL. As an outlook, research implications and possible generalisations of the present research framework will be discussed.

Introduction: Background, Purpose and Rationale

Starting point of the present work are two long standing problems of physics, other science and general learning1. The first is the problem missing transfer, or of ‘inert knowledge’ (Renkl et al 1996, Whitehead 1929), quite strikingly confirmed especially for Germany (Baumert et al 2001, 2002): students’ performance in transfer of knowledge, in particular to real-life contexts, is found wanting. Moreover, science related motivation of pupils is generally low, see e.g. the ROSE (focus: attitude/motivation; Sjoberg & Schreiber, 2010) and PISA (see e.g. OECD, 2006) large scale assessments.

Context-based physics (science1) learning (CBPL) has been proposed and is currently intensively discussed to counter these (and other) problems (Fensham, 2009; Bennett et al., 2007; Parchmann et al., 2006, Waddington, 2005). In a broad understanding of the term, CBPL is understood as “using concepts and process skills in real-life contexts that are relevant to students from diverse backgrounds” (Glynn & Koballa, 2005, p. 75). Making (or trying to do so) science issues relevant to students themselves, their families and their peers is opposed to the wide-spread perception of especially physics (or more generally: science) as

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1 The focus in the present contribution is on physics education, but it is understood that much of the discussion can be transferred to science education general, even though not mentioned every time explicitly.
being dry, impersonal and irrelevant, and this is supposed to have positive effects both on motivation and learning (Bennet, Lubben & Hogarth, 2007).

The present contribution pursues this line of research and development and aims at combining the general approach of CBPL with a specific format of establishing contexts, viz. “stories as context”. Beginning, embedding, and connecting teaching content and sequences with an interesting story is a promising way of relating it to contexts beyond school, which is current and good practice in many science and non-science classrooms. A particular form for that are newspaper story problems (NSP). These are problems related to newspaper articles containing science related issues, and which are (up to minor modifications) unchanged in both text and layout (see Figure 1).

From a practical point of view, the double rationale behind NSP is that (i) newspapers and newspaper articles as such stand for out-of-school, real-life contexts per se and (ii) journalists are supposed to be experts for writing interesting, good stories (so it is good advice to draw on this know-how). Good practice reports about successful realisations and existing collections of examples of using newspapers for mathematics and science literacy purposes are available, both on the international and several national levels (extensively in mathematics, see e.g. Herget & Scholz, 1998; Paulos, 1995;), and to a lesser extent in physics education (Armbrust, 2001). Jarman and McClune (2007) give an excellent introduction with many examples about the use of newspapers in science education.

A common feature central to most variants of both context-based and learning is “authenticity”: A quite widespread, basic understanding of “authentic” learning (starting with the word origin: gr. authentikós „true”; lat. authenticus „reliable”) is that it should be related to actual, real(istic), genuine situations and experiences learners are supposed to encounter. This is e.g. the understanding assumed by PISA (OECD, 2006): it repeatedly states the usage and value of tasks and problems (items) „that could be part of the actual experience or practice of the participant in some real-world setting”, and it „places most value on tasks that could be encountered in a variety of real-world situations”. Note that even such a basic understanding of “authenticity” is far from being trivial or educationally shallow. PISA (OECD, 2006) states two important points about that: First, such problems, to be encountered in real-world settings (“factual authenticity”), are usually not stated in the disciplinary terms to be learned or applied. Thus, a work of „translation“ with terminological and conceptual reframing has to be carried out, representing a first step of cognitive activation. Second, the disciplinary content involved (mathematics or science) is „genuinely directed to solving the problem”, i.e. learners can perceive that there is a real-world problem for the solution of which some content of science or math is necessary (problem authenticity), instead of the problem being just an (invented, artificial) occasion to practise this content.

Starting out from the background explained above, the present study aimed at investigating Newspaper Story Problems as a promising way of combining contextualisation and authenticity with the practicability and flexibility offered by the easy-to-have and easy-to-deal-with medium “newspaper”.

Research questions within this approach are as follows:

**RQ1**: Does the context-based learning based on Newspaper Story Problems actually show the above-mentioned general

a) motivational and

b) learning benefits?

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1 More explicitly stated in the mathematics part of PISA (OECD, 2006), but applying to science as well (cf. e.g. the in-depth analysis of Fensham (2009)).

2 There is a considerable body of literature on various extensions and refinements of “authentic learning”, a review of which goes beyond the focus of the present article; we do want to give, however, some hints about this larger framework, for those who might be interested: see e.g. the thorough analyses of Muckenfuß (1996) and Cariou (2010) about relation of authenticity to meaningfulness and scientific methodology, respectively, and of Shaffer and Resnick (1999) about a multi-component understanding of authenticity.
Lausanne/ngn. Another great round-a-world adventure a la Steve Fossett’s solo flight last month. Now it seems the explorer Bertrand Piccard will attempt the world’s first solar powered around the world flight.

Piccard comes from a family of explorers and made history in March of 1999 with a nonstop, around-the-world flight in a hot-air balloon, the Breitling Orbiter 3. But what about the solar power side of this? Is that really possible? Nearly the entire body of the plane will be covered by 287 square yards (240 square metres) of solar panels. Piccard estimates that enough power can be generated to sustain a flight of roughly 60 miles an hour (97 kilometres an hour). The plane’s batteries are going to have to be pretty heavy, capable of storing 200 watts per kilogram, so that the plane can run at night.

Gadling, 2005-04-13

1. How long will Bertrand Piccard be on his way around the world?
2. How much electrical energy per kilogram and how much power per kilogram has to be produced at least?
3. How much electrical energy per kilogram and how much power per kilogram has to be produced at least by the solar panels, if Piccard will drive ca. 75% of the flight by day?
4. How much electrical energy per kilogram has to be produced at least by the batteries?
5. Discuss your results critically, e.g. with respect to the energy transformation process, and use physical arguments thereto.

In 2007 the explorer Bertrand Piccard will attempt the world’s first solar powered around the world flight. He estimates that the solar panels of the plane can generated enough power to sustain a flight of roughly 60 miles an hour (97 kilometres an hour). The plane’s batteries are going to have to be pretty heavy, capable of storing 200 watts per kilogram, so that the plane can run at night.

RQ2: Moreover, does the NSP approach foster in particular two features playing an essential role in the background discussed above, viz.

a) perceived authenticity and reality connection (as motivation component) and
b) transfer (as learning component)?

RQ3: Finally, can such potentially positive effects be established

a) for more than short-term duration (temporal stability) and
b) for a broader selection of learners and learning conditions (“robustness“)?

In view of the large role classroom applicability had for our research objectives, the study was carried out as quasi-experimental design, using well-established or thoroughly validated instruments, in order to deal with RQ1 and 2. Moreover, the involved repeated measures and various covariates, in order to deal with the questions of temporal stability and robustness, respectively (RQ3). A detailed description of design, materials and instruments follows in the next section.

**Materials and Methods**

**Study Sample and Procedure.** The study was conducted in a broad sample (911 students, 39 classes, 15 teachers, 10 different schools). Two conditions of learning were compared in a quasi-experimental pre-post-test study with repeated measure design (see Table 1).

While control group classes (CG) worked on traditional problems, treatment group classes (TG) worked with NSP (with exactly the same physic content and questions to work with, see Figure 1). Subject matters were energy and energy transformations (grades 9/10) and elementary kinematics (grades 7/8).
The instruction followed the design presented in Table 1. The two groups worked on different worksheets containing tasks (dealing with energy or kinematics). Learning content and difficulty (as rated by a physics teaching expert panel; see below) in the two conditions were identical. The MAI ‘newspaper-tasks’ in the TG differed from the tasks in the CG only in language style (newspaper vs. textbook) and in their layout, but were identical in the basis information, and the questions related to it (see Figure 1). The treatment of the worksheets and tests were identical in TG and CG. Duration of pupils work on each worksheet as two school lessons, each of which 45 minutes.

<table>
<thead>
<tr>
<th>Week</th>
<th>Control Group (CG)</th>
<th>Treatment Group (TG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tests of non-verbal intelligence and reading comprehension</td>
<td>Tests of non-verbal intelligence and reading comprehension</td>
</tr>
<tr>
<td></td>
<td>Motivation pre-test (MOT1-PRE)</td>
<td>Motivation pre-test (MOT1-PRE)</td>
</tr>
<tr>
<td>2</td>
<td>Worksheet 1</td>
<td>Worksheet 1</td>
</tr>
<tr>
<td>3</td>
<td>Worksheet 2</td>
<td>Worksheet 2</td>
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<tr>
<td>4</td>
<td>Worksheet 3</td>
<td>Worksheet 3</td>
</tr>
<tr>
<td>5</td>
<td>Immediate motivation test (MOT2-POST)</td>
<td>Immediate motivation test (MOT2-POST)</td>
</tr>
<tr>
<td>6...13</td>
<td>Achievement test</td>
<td>Achievement test</td>
</tr>
<tr>
<td>14</td>
<td>Follow-up motivation test (MOT3-FUP)</td>
<td>Follow-up motivation test (MOT3-FUP)</td>
</tr>
</tbody>
</table>

**Table 1.** Study and teaching procedure

In order to control for teacher influence, TG and CG classes were taught by the same teacher.

Moreover, in two related studies, two other control measures for a possible teacher engagement and Hawthorne effects were taken: First, pupils were asked after the intervention about an uncommon degree of engagement of their teachers in the TG lessons (Vogt, 2010). Second, the design was changed to a one-and-a-half blind design (Kuhn, 2010), where the CG and TG pupils belonged to the same class split in half and working simultaneously on their respective work sheets, not knowing that there was a difference; the teacher knew, but did not intervene in the independent pupils learning phases (week 2-4, see Table 1). Thus, pupils were “blind” (preventing a Hawthorne effect), the teacher not really “blind”, though she could not influence the learning (preventing an engagement effect).

**Materials and Instruments.** Repeated measures of motivation were carried out with an instrument well established in the in the literature on science motivation (adapted from Hoffmann, Häußler & Peters-Haft, 1997; total Cronbach’s α = .93) with the following subscales: Intrinsic motivation (MI; eight items; Cronbach’s α = .89), reality connection/authenticity (RA; eight items; Cronbach’s α = .95) and self efficacy/self concept (SE; ten items; Cronbach’s α = .89). Measurements ware made before (pretest), immediately after (posttest) and seven weeks after (follow-up test) treatment (for details: see Kuhn, 2010).

Achievement was tested with a written test with five items, with difficulties similar to those of the worksheets of the training period. Three of these five tasks corresponded to the PISA competence levels III and IV (transfer level), the other two tasks to the level I and II. The competence levels were assessed by an expert rating (Cohen’s Kappa κ > .78).
Covariate measures. Prior achievement in physics was assessed as average grade level (average marks in written physics tests) of each student in first six months prior to intervention. Reading comprehension (Lang, Mengelkamp & Jäger, 2004) and non-verbal intelligence (Kornmann & Horn, 2001) were assessed by standardized measures and taken into consideration as covariates, too.

Analysis method. According to the variable plan, the hierarchical sample structure and design described above, statistical analysis was carried out by a 3-level-Hierarchical Linear Modelling was applied (using HLM 6.0; see Raudenbush et al., 2004). Due to the repeated measure design with three testing times, level 1 through 3 for the analysis of the motivation data is given by measuring times, learners (and their characteristics) and classes, respectively (the latter comprising in particular the treatment forms: CG, TG classes). For the analysis of the learning data (only two measurement times), the levels are learners, classes and teachers, respectively. For all motivation and learning results reported below, the significance values ($p$) were computed according to this method.

Data and findings

Because of the complexity of the study only a selection of relevant results is presented in this synopsis (for further information: see Kuhn, 2010). Effect sizes are expressed as Cohen’s $d$ (see Cohen (1988), with the conventional assignment of small, medium and large effects as $0.2 < d < 0.5$, $0.5 \leq d < 0.8$ and $0.8 \leq d$, respectively). As one is interested in the effect sizes at the post-test and follow-up-test separately, which are not available within Hierarchical Linear Modelling, the values reported below were computed at the basis of averages and standard deviations obtained at post and follow-up test according to the standard definition of $d = (M_{TG} - M_{CG})/SD_p$, where $M_{TG}$, $M_{CG}$ and $SD_p$ are treatment/control group average, and $SD_p$ the pooled standard deviation (see Cohen (1988)).

Achievement results are given separately for the two subject matters investigated, as the achievement tests obviously were different ($V$: velocity, elementary kinematics; $E$: energy and energy conversion), whereas motivation results are given as aggregated over both subject matters (as the motivation test was identical). Comparing the treatment and control group, one finds:

- **Motivation**: statistically highly significant difference, with large effect sizes ($p < 0.001$; $d = 1.66$)
- **Motivation subscale reality connection/authenticity (RA)**: as above ($p < 0.001$, $d = 2.03$)
- **Achievement**: as above (overall: $p < 0.001$, $d(V/E) = 0.91/1.18$; transfer: $p < 0.001$, $d(V/E) = 0.96/1.31$)
- **(Temporal) stability**: improvements last at least for several months (motivation: $p < 0.001$; $d = 1.04$ after 3½ months, achievement: $p < 0.001$; $d = 2.15$ after 2½ months)
- **Robustness**: no (or weak) dependence on gender, reading competence, cognitive ability, class and school characteristics were found.

Moreover, no difference of teacher engagement (Vogt, 2010) or between the results of the present study and the related 1½-blind study (see sect. 2 and Kuhn, 2010) were found.

Discussion and Conclusions

The results of a large sample, quasi-experimental intervention study using Newspaper Story Problems as a specific form of context based physics education showed large positive effects on pupils’ motivation and learning, thus answering positively to research question 1. Effects are statistically highly significant and very large in terms of effect sizes as measure of practical importance, both for overall achievement and motivation ($p < 0.001$; $d = 1.66$ and $p < 0.001$; $d(V/E)=0.91/1.18$, respectively).

This holds also in particular for transfer, as specific component of learning, and perceived authenticity, as specific component of motivation ($p < 0.001$; $d = 2.03$ and $p < 0.001$; $d (V/E)= 0.96/1.31$, respectively). Thus two basic issues for the whole “context based learning” school of thought, i.e. perceived authenticity (as opposed to merely “outside” or “assumed”) as an essential motivation factor and transfer as a central learning objective turn out to be achieved within the present approach, giving a positive answer to research...
question 2 as well. Moreover, all positive effects are stable at least for several months. These positive
effects are also “robust” in the sense of being not (or weakly) affected by possible influence factors on
the individual (gender, various grades, pre-motivation and pre-knowledge) and classroom/school (various
teachers, schools and school types) level. Thus there is a positive answer to research question 3 about
temporal stability and robustness, within the limits of duration and factors considered in the present
study.

In sum, NSP had large positive, robust and temporally stable effects on student both motivation and
learning. Together with its practicability and flexibility, this implies a desirable degree of “classroom
usability”.

The control measures undertaken for a possible teacher engagement or Hawthorne effect (see above)
showed no influences of this kind on the effects found. Moreover existing meta-analytic research found
small to no evidence for various kind of Hawthorne effects (Adair, Sharpe & Huynh, 1989), with the largest
value of $d = 0.3$ reported for a possible influence by increased attention. In contrast to this, effects sizes
found in present study are (very) large, with values of $d$ ranging around 1 and above, incompatible with
the available evidence on the Hawthorne effect.

The conceptual and methodological framework explained in sect. 1 and 2 offers a useful starting point for
research on further variants of and more detailed hypotheses, and we will end with an outlook on some of
these, and on some open questions.

**Physics around a water-cooker**

In order to make tea, two litres of water have to be
brought to boiling with the help of an electric water-
cooker (see fig.).

a) Is this possible in less than six minutes, as claimed in the advertisement?

b) What is the prize for heating the tea water, given a price of 20 cent per kilowatt hour?

c) How large is the electric current flowing through the heating element?

d) Determine the electrical resistance of the heating element!

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*Figure 2. Advertisement problem’ format for the topic of ‘heat’ and ‘heat capacity’. Again, tasks are identical in the corresponding control group (as for NSP).*

From the positive experiences made with NSP, it can be hypothesized that similar effects can be obtained
by other types of learning media of this type, and several ongoing studies (see Müller et al, 2010; Kuhn
et al, 2010) deal with this question: Quite similarly to newspaper story problems, advertisements with
some physics (or more generally, science related) content can be used to provide learning material and
opportunities with a focus on real-world connections; an example of such an “advertisement problem”
is shown in Fig. 2, and a thorough investigation as already carried out (see Vogt (2010) for a detailed
account). Another example are tasks and exercises with esthetically appealing pictures related to physics
content, as familiar e.g. from astronomy photographs; for examples, see Müller, 2011, 2012; for a study
on this issue; Lenzner, Schnottz & Müller (2012).

A limitation for the present study is that it does not deal with higher order competences such as problem
solving or critical thinking in general and critical reading of science related media reports in particular
(Norris & Phillips, 1994, Millar & Osborne, 1998). The main objective of the present work was to establish,
whether NSP have enough effectiveness to be of practical importance, which seems to us an important

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issue, looking at the generally quite small, zero or even negative effect sizes reported for existing context-based science learning interventions (Bennett, Lubben & Hogarth, 2007; Taasoobshirazi & Carr, 2008). Taking it now as starting point, with increased confidence in its basic effectiveness, it is possible and important to go beyond this limitation. Thus, we started work to include assessment for higher-order competences, in particular on critical thinking, based on existing research (Kirikkaya & Bozkurt, 2011, McClune & Jarman, 2010). Finally, various other questions of interest on more detailed features of the approach and its implementation can be studied on the basis of the experience and material developed so far, such as the influence of problem complexity (Kuhn, 2010) or the “dose” (duration) of the intervention necessary to achieve the desired effects (Vogt, 2010). Research of this kind is under way, always with a close eye on classroom application.

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Using Common Formative Assessments with Middle and High School Students to Inform Pedagogical Approaches for Teaching Scientific Content

Gordon J. Aubrecht, II, Department of Physics, Ohio State University Marion, Marion, Ohio USA, aubrecht.1@osu.edu
Bill Schmitt, Science Center of Inquiry, Fountain Hills, Arizona, USA
Jennifer Esswein, Department of Physics, Ohio State University, Columbus Ohio, USA

Abstract

As stated in *A Framework for K-12 Science Education*, the United States is falling behind other countries and its own past achievements in science education; it is imperative that approaches to teaching science not only be engaging, but also provide the necessary foundations to create a citizenry that can solve humanity’s current and future challenges. As a result, U.S. science standards for K-12 are being reformed at state and national levels so it is becoming increasingly important to conduct real-time research to inform teaching strategies. Formative assessments can allow teachers to immediately understand what is and is not working in their classrooms for the purpose of changing how they teach various content. This study presents a model, as well as its application, for the development of formative assessments in the classroom in a rurally located, city high-needs district in the state of Ohio. The authors wrote formative assessments (CFAs) for the teachers in seven categories: sixth grade, seventh grade, and eighth grade for the middle school, and physical science, biology, environmental science, and physics for the high school. Teachers had the opportunity to provide feedback, the CFAs were changed if necessary, and then they analyzed the CFA at the both the beginning and the end of the quarter. The emphasis in the analysis was on what student thinking as expressed in writing reveals. The pretests reveal what students think at the beginning, giving the teacher an idea of what ideas might already exist, right or wrong; the posttest should reveal to the teacher whether the instruction succeeded. Results indicate changes not only in the way teachers view their pedagogical approaches, but also in how teachers consider student personal epistemologies.

Introduction

We call our project IMPACT. That acronym stands for *Inquiry Model for Professional Action and Content-rich Teaching*. The first three years of the project were run by Gordon Aubrecht and Bill Schmitt from the Science Center of Inquiry. Dr. Esswein joined as evaluator this past year.

For the past 4 years we have been working with Marion City Schools to help the middle and high school teachers improve student learning by systemically incorporating standards-based and inquiry-driven approaches. The school district has a history of low student performance and both the teachers and administrators were looking for ways to increase performance.

The project began by making professional (content) development available for teachers during the summer and also extensively during the regular school day during the school year. We also worked with the school to incorporate FOSS science in the middle school because it naturally supports inquiry teaching and learning approaches. Two years ago the high school physical science and biology teachers were added to the project.

The two parts of our earlier work involved providing content and encouraging teachers to work together collectively on building or changing their lessons in the context of state standards. The professional development involving content and pedagogy was introduced during a summer session through inquiry and allowing teachers to experience it for themselves with followup throughout the school year; the lesson development during the school year occurs through grade-level teachers working together in groups. We encouraged teachers to value student expression and use what they heard to change their lessons.
While we have experienced some success, we wanted to make the process more formal. The school district is under a form of academic watch, and the state wanted the district to institute formative assessments. This gave us an opportunity to add an effort to use formative assessments as part of our program.

Many school administrators appear not to understand the difference between summative and formative assessment and have actively prevented true formative assessment from occurring. The teachers in this case proceed to “give them what they want,” summative assessment, with no useful effect. This is partly from lack of knowledge of what they could as teachers gain from what students think and partly from a reluctance to spend time on something they consider another useless administrative demand.

**Summative assessment** tells us as teachers whether the kids “got it” or not.

**Formative assessment** tells us more about the reasons they got it or did not “get it.”

We see formative assessment as a vehicle to better understand student reasoning and existing ideas so we can better connect to the students from where they are and create better relevance. Formative assessment is mostly about “listening” to students’ thinking and responding to it in our curriculum planning and teaching. The mandate for formative assessment gave us an entrée to use this as a third piece of our approach.

**Methods**

During the school year 2011-2012, we added formative assessment to content support and teacher lesson-building. From the first we realized that there was a major obstacle to making this work because very few people in the system had any idea about what formative assessment is and how it differs from summative assessment. It seems that most of us, as teachers, think of any assessment only as summative and use it to judge a student’s knowledge by grading the test.

The assessments are common to a grade level in the idle school and to course material in high school, and so are “common formative assessments” and design of the assessments originally rested on the staff rather than the teachers for two reasons: first, teachers were most accustomed to use of multiple choice instruments, while we think that questions that are open-ended and require thought and ability to express the thought in writing are more appropriate to elicit student thought; and second, teachers were used to teaching material in their own way with a nod to state standards rather than exploring the reasons the state had developed the standards in the first place.

Formative assessments can allow teachers to understand what is and is not working in their classrooms for the purpose of changing how they teach various content. We recognized that reading and analyzing the students writing (sometimes extremely hard to decipher) and assembling it in a reasonable narrative is likely to be time-consuming. Teachers who are skeptical (they all were) need an extra inducement to put in the extraordinary effort we were asking for. We put money in our grant (and it was approved by the Ohio Department of Education) to pay teachers for their analyses—$200 for the pretest and $200 for the posttest.

We wrote teachers about what sort of information we were interested in and that we hoped they would provide in their CFAs:

“The purpose of the analysis is to find out what you have learned about how your students think about the subject you are teaching, from your students, prior to teaching it (for the pretest) and after you have finished teaching it, along with what this means to your teaching to the current class (e.g., ‘I plan to reteach X because it was clear there was no progress from the pretest, and the way I plan to do so is ...’); or classes of the future (e.g., ‘Given this year’s experience, next year I plan to do Y because ...’).”

“In all cases we (Gordon and Bill) are interested in hearing the voices of your students in the analyses. For example, we would like quotes that demonstrate student thinking, whether accurate or inaccurate, insightful or misled. The greatest value to be gained from these analyses is about how your students are thinking / reasoning rather than just giving a score to the students. This is what can help you as a teacher to think about how what you’ve learned from the students will be used in future classes.”

*WCPE 2012, Istanbul, Turkey*
**Data and findings**

Most teachers do not have much of an idea about what formative assessment looks like or why it is used. The first impression of most teachers is that this is just a test to see how well kids do and give the teacher information on what to teach with very little information on how to teach it.

It took most of this school year to help our teachers understand formative assessment and, when they did, the results were outstanding for the teachers professionally and personally.

One high school teacher noted that “[f]or me, the CFA’s were a process which I sincerely did not understand in the beginning yet tolerated them for the money. They are time consuming, difficult to read, and if you are not part of the development process, which I chose not to be, it does not have as much meaning. Being fair, I think the whole thing was a difficult learning experience due to the interference by the administration who really does not understand what is trying to be achieved by a common formative assessment.” This teacher added, “Through the whole process I could not get it straight that I WAS NOT BEING EVALUATED on my teaching methods, but [that] I was trying to understand how students actually thought about the topic under study. The problem I am having is transferring this process into my planning which occurs due to the lack of time (the extensive time it takes to go through the CFA process). Quite frankly, I know we are onto something, but the way school is structured is antithetical to our goal. The daily grind of five or six classes in a row, huge numbers of students who could[n’t] care less about learning, and the idea that the administration actually knows what learning and the teaching process is about hamstrings the process.”

**Figure 1.** shows examples of CFA questions that were asked.

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**CFA for Grant eighth grade first quarter 2011**

1. The graph below is of position versus time. Suppose it is for a walk Jimmy made with his friend.

![Graph Image]

a. Tell the story of what Jimmy and his friend did on their walk.

b. Make a ball out of a piece of aluminum foil the same way you would make a snowball. Closely observe the ball. Then squash the aluminum foil ball by stepping or stomping on it and then observe it again. Answer the questions below to tell how the ball changed after you stepped on it:

   A. Tell if the shape of the ball changed and explain your answer.
   
   B. Tell if the volume of the ball changed and explain your answer.
   
   C. Tell if the weight of the ball changed and explain your answer.
   
   D. Tell if the mass of the ball changed and explain your answer.
c. Imagine you had a message in a bottle that you put in a stream in Marion, Ohio and let it float away so someone else could find it. Also imagine that the bottle could float in the water all the way to the ocean. Write a short story about the journey of the bottle. You could tell what your message said and where the bottle went and where it may wash up on a beach.

d. Our Sun is a star that happens to be close to Earth. Astronomers, such as Dennis, believe that stars like the Sun have a life cycle and that they are formed or “born” they eventually “die” out.

A. Describe what you think a new star in the process of formation (i.e., a “baby” star) would look like and tell why you think it looks the way it does?

B. Describe what you think a dying star would look like in the process of dying and tell why you think it looks the way it does?

C. What kind of matter are stars mostly made from?

e. Patty said that all the parts of her body are made of cells. Deon said that could not be right because there are parts of the body that are not made of cells. What do you think?

A. Name two parts of your body that are made of cells.

B. Name two parts of your body that are not made of cells.

Figure 1. a. Eighth grade CFA question. b. Sixth grade CFA question. c. Seventh grade CFA question. d. High school physical science CFA question. e. High school biological science CFA question.

A middle school teacher wrote “I was not a fan of this [CFAs] and knew in my heart that it was a waste of time and nothing but another source of stress for the students and myself. But I tried it out and paid attention to what was put on the paper when I graded my student’s work. I was amazed at what was being written. Not correct answers and information spit back to me but actual thoughts—good, bad, or indifferent—and ways of thinking about concepts I hadn’t taken into consideration. It was interesting to see what misconceptions my students had and what misconceptions did or didn’t change over the course of a 9 week period.”

Teacher analyses were varied, as the questions asked in Fig. 1 show. Teacher comments were revealing. We present a selection below.

A sixth-grade teacher: “Students have one idea about water—bodies of water—they are all connected to the ocean and that sand is just sand … Soil is soil and it is just there. Students have confusion about volume and mass. Air having mass (any properties) really throws them. They need hands-on investigations BEFORE 6th grade to get them thinking about the difference between mass and volume.”

A biology teacher: “I found that students didn’t think there were wild animals in their neighborhood at first. They could only tell me about dogs and cats. I was shocked by this on the pretest. This insight helped me so we could discuss what types of animals might be found in their neighborhood so we could make our food webs.”

A seventh-grade teacher: “One insight ... was that I found that students struggled with the WHY about how the revolving moon makes moon phases. They wanted to tell me that it was because parts of the moon disappeared somehow during its revolution.”

A seventh-grade teacher: “The [CFA] showed me how little students understood on how the body releases energy before the test. I was impressed by their gains on these questions on the posttest.”

An eighth-grade teacher: “The [CFA] showed the students had a decent understanding on the graphing skills. The motion story graph was difficult for them. ... I would say that I really enjoyed reading student thoughts. I liked their motion graphs and the stories they tried to make up about the graphs.”

An eighth-grade teacher: “For quarter 2, students’ thoughts were pretty good regarding forces. I was encouraged that they already had some correct assumptions regarding force and motion.”

A physical science teacher: “ [S]tudents didn’t really make a true connection about what was actually happening to the salt in the water. Even though the word dissolved was used in the opening statement. ... It became evident they really did not know or have a solid understanding of the PROCESS.”
A physical science teacher: “[T]he majority of the students did not have a clear model that they ‘owned’ regarding atoms.”

A physical science teacher: “Some students thought that the water and salt were connected forever after mixing. When water evaporated, the salt went with it.”

The observations show that teachers did, in fact, take the CFAs seriously, and used them to reflect on their students and their own teaching.

Anecdotal evidence says that the initiative needs to last at least a few years to be sustainable. Research has shown that it requires at least 120 hours of intervention to make a permanent change (Reeves, 2009; Stereim and Vissa, 2002).

Our program is supplying both those conditions. Aubrecht and Schmitt have invested over 5000 hours working on the program over the first four years. Most middle school teachers who participated in the summer programs have accumulated about 600 hours of intervention; the other teachers have experienced around 300 hours of intervention over four years. High school teachers have—between meetings and observations—about 500 hours of intervention over two years.

We have results that show we are accomplishing things. The Ohio Academic Assessment (OAA) Science scores from 2008 (the year prior to the start of our program) through 2012 are shown in Fig. 2. Note that even the low year 2011 (a class with a comparatively huge number of IEPs) was higher than in 2008, the year before our program began. Marion middle school students did much more poorly on the OAA than other Ohio middle school students. Eighth grade students in Ohio rated ‘proficient’ or above were at 62.8% in the 2008-09 school year, 64.8% in 2009-10 school year, and 67.4% in the 2010-11 school year, while no statewide data were available for the 2011-12 school year as of this writing.

![Figure 2. OAA science scores of middle school students who were rated “proficient” or above.](image)

![Figure 3. OGT scores of high school students who were middle school students the first year of our program who were rated “proficient” or above.](image)
The 2010-2011 Ohio Graduation Test (OGT) was given to the first group of students who had come through at least one year of instruction in our program. Fig. 3 shows the results for the Marion high school sophomores’ testing. Note the ~8-10% step visible in all categories for Marion City Schools tenth-graders. It must be admitted that all-Ohio results were consistently much higher than either of these results. In the 2008-09 school year - 52.4% were rated ‘proficient’ or above in Marion, while statewide, 76% were rated ‘proficient’ or above; in the 2009-10 school year, 54.9% were rated ‘proficient’ or above, while statewide, 73% were rated ‘proficient’ or above; in the 2010-2011 school year, 63% were rated ‘proficient’ or above on this test, while statewide, 74.7% were rated ‘proficient’ or above; and for the 2011-12 school year, preliminary data show that 61.1% in Marion were rated ‘proficient’ or above (no data for statewide results are as yet available).

The Marion City Schools received funds from the “Race to the Top” program, which involved the schools providing data on the results at each grade level. The school district chose to use commercially-available Terra Nova tests. The test was given for the first time during the 2011-12 school year, and shows that 6th grade ranked in the nationwide average range (51.2%) as did 7th grade (52.0%).

One teacher wrote: “I think the performance record of the students is proof for itself when it comes to the impact the grant has had on our school district. The inquiry-based instruction has really brought about the developmental process that was missing from our district for the first couple years I was here. I have noticed the difference in my classroom considering I have at-risk students who come from very low socioeconomic standards. It has allowed them to not be limited to their home life or economic situation, but instead to flourish academically and prove that they can do science—that they do have self-worth. To me, the impact of the grant has implications far beyond just a classroom. We are trying to change the face of a community in dire straits and we are trying to do this through academic success.”

A paired t-test showed significant gains after treatment in student answers to multiple choice assessments at the middle school during the 2011-12 school year (t = 2.798, df = 9, p = 0.021) indicating an increase in scientific reasoning ability.

Due to intervention, participating teachers had an increase in scientific reasoning ability as measured by The Classroom Test of Scientific Reasoning (CTSR) (A. Lawson, 2000). Based on Piagetian levels of cognitive demand, the multiple choice test includes pairs of questions, in which one covers a content topic (such as probability or control of variables), and the second requires the person provide the reasoning for the answer choice. Program teachers completed the CTSR both in the fall of 2011 and again in the spring of 2012.

**Discussion and Conclusions**

The project began in Grant Middle School (grades 6, 7, and 8). The science teachers met before classes began for two weeks. The district had bought FOSS kits, which often sit unused on shelves. We determined that unpacking the kits by doing them was the best way to deal with the situation given us. With that beginning, we worked the first year to bring content support to the teachers, to encourage them to talk with students and listen to what they said, and to help them be more active as learners.

The next summer, we brought teachers to Ohio State’s Stone Laboratory on Lake Erie just before school began to study glacial grooves, wildlife, and indigenous plants. (Most middle school teachers teach some biology.)

Instruction in content continued, as did emphasis on inquiry. Teachers slowly changed. We noted this success when students (and parents) who had entered high school from eighth grade complained that science had turned uninteresting.

As a result, the third year of the project, the school administration made the high school teachers join in. We did a two-week workshop with the high school teachers during summer 2010, emphasizing ideas that teachers could use to involve students, such as oobleck (cornstarch and water) and measuring properties of bouncing balls.
During the school year, we attempted with limited success to encourage teachers to attend professional meetings and present their experiences. High school teachers went to Stone Laboratory in June 2011 (one middle school teacher also went). Shortly before school began in August, 2011, we held two weeklong workshops, one for physical science and one for biology teachers.

A skeptical teacher wrote, “This was my first year associated with the grant. However, this is my 18th year of teaching and so I consider myself a veteran teacher. The focus of the grant was to help me to develop inquiry science teaching. To be honest I was skeptical. I have witnessed inquiry teaching not done well. Instructors who are simply lazy and throw out equipment and or ideas and ask the students to just investigate.”

The teacher continues, “I will not say that I whole-heartedly embrace all inquiry teaching but it has caused me to approach teaching a little more opened minded. I now see more value of having students use inquiry as a method of learning. One way in which I have a changed my teaching is to ask myself; ‘Can I avoid just telling or explaining something?’ and instead have the students see it, touch it or experience it.”

Teachers averred that the program has made a difference. One middle school teacher wrote “This new system allowed me to change my approach to student evaluation. I concerned myself with how the students processed information and how they came to gain knowledge instead of how many ‘right answers’ they were able to tell me. Because of this I feel that my students felt success even as they were asked to do and redo work. I hope to improve this system next school year and allow more opportunities for the students to evaluate themselves.”

Another middle school teacher wrote, “I have allowed myself to let my students guide the majority of their learning, to ‘not’ answer directly the queries of my students, which creates an atmosphere of questioning that is undirected and may take one path or several paths during each class period. I have seen enthusiasm in my classroom grow and be nurtured and seeing that enthusiasm is very rewarding.”

The new Ohio science standards emphasize Science Inquiry and Application as a standard for how students learn content. The program strongly focuses on achieving these as well as all the specific content standards.

Marion City Schools are in a difficult situation, with around 80% of students eligible for free or reduced-cost lunch and a poverty rate near 40%; Marion City Schools is a high poverty district. Marion City Schools is classified as a high-need district by the Ohio Board of Regents. As part of the rustbelt, Marion has few jobs for unskilled labor, many unskilled laborers, and a lack of skilled labor. Many residents are mired in poverty, and about two-thirds of pupils are eligible for reduced-cost or free lunches. The proportion of minorities in the schools is small (~5%). Grant Middle School enrolls all sixth-, seventh- and eighth-graders in the City Schools. Harding High School is the district’s sole high school. This widespread poverty makes everything difficult for these schools, which try mightily to remedy the problems students have and to encourage learning.

Over half of Grant Middle School students who score at the “limited” level of proficiency have learning disabilities; almost one-third of students struggle with limited English language proficiency. At the “basic” level, many students have learning disabilities and a lot of them also have limited English Proficiency. Teachers have many such students in their classes. Nevertheless, they have seen successes as a result of this intervention program.

A middle school teacher confessed: “Through all of this I learned one of the greatest lessons. I learned how to step back and let my students do the learning without me telling them everything I wanted them to know. It’s amazing what kids will learn and come up with when they are able to investigate on their own without the intervention of the teacher. I always thought that I was a facilitator of learning. In reality I was a teacher who occasionally stepped back during carefully controls and planned labs; not really a facilitator at all.” This teacher experienced something new and different and grew as a teacher as a result.

We think that the CFAs encouraged better teacher comprehension of the difficulties faced by students. For example, physical science teachers at the high school found out that, after an extensive effort to meet the standards related to atoms, students seemed to know vocabulary but, when asked to explain atoms in their own words, showed extremely limited understanding. By “listening” to the student explanations, teachers concluded that a fundamental problem was that students had no mental conceptual model to
explain the atom and were thus not able think about atoms within a context that made any sense to them. As a result of their analysis of student reasoning, the teachers decided that they really needed to reform how students were learning about atomic structure and completely revised their first quarter curriculum for the current school year. While results are not yet available, the initial response is very encouraging.

We think that the Marion results suggest that the race to top can be greatly enhanced when teachers and students reflect on personal reasoning that enables knowing. Student understanding through reasoning is the most powerful method for students to find meaning in a way that allows them to improve their ability to find relevance and to view the world differently.

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Cognitive Test as a Tool for Physics Learning

Konstantin Rogozin, Department of Experimental physics, Altai State Technological University, Barnaul, Russia
Sergey Kuznetsov, Department of Physical Technological Institute, National research Tomsk Polytechnic University, Tomsk, Russia
Diana Kondrashova, Department of Experimental physics, Altai State Technological University, Barnaul, Russia
Irina Lisina, Department of Experimental physics, Altai State Technological University, Barnaul, Russia

Abstract

Network instruments for learning physics allow using all Internet information resources accumulated by Humanity and learn physics using PCs, tablets and mobile phones at any place and at any convenient time. Multimedia network instruments are able to create special physics learning spaces where students get a sufficient amount of information; are offered up-to date computer instruments for decision-making; get physics competences through the use of new cognitive technologies. The importance of the task of creating special physics learning spaces is connected with two main aspects: the use of new approaches and methods in Physics teaching based on Multimedia network instruments, increasing students’ motivation; the “infusion” in a teaching learning process new methods of organizing physics content, showing that it may become a good cognitive tool promoting the fundamental approach to the scientific methodology. Four types of tests are: “Physics knowledge check”; “Physics formula check”; “Physics problems solution”; “Physics experiments simulation”. Four types of tasks are usually used: “Direct choice”; “Logical choice”; “Multiple choices”; “Puzzle choice”. One of the most important points is the amount of number attempts given to students to pass the tests. The minimum number of the unique variants in each tests formed randomly from the base of not less than ten billion, so students can be offered any reasonable number of attempts. For students, cognitive tests are intellectual games, and the result is getting competences and real score (in points) that can be improved by further attempts. Cognitive technology can combine process of getting knowledge, skills and a control procedure. With such an approach testing becomes a tool of physics learning. From our experience, students are ready, able and willing to work in accordance with the proposed algorithm.

Introduction

We have been professors of physics for almost 30 years. During this time students have not become better, nor have they become worse. In many ways they are just different from their peers from 30 years ago. They are the next generation. They are the generation of computer games. So, we have to offer them a choice of learning physics as a computer intellectual game. One of the possible intellectual games is cognitive test.

This story was told to us (Taşar, Bilici & Fettahloğu, 2012) by David Hestenes earlier this year. In the 1990’s at the same time four American university professors were teaching the same course in physics – Mechanics. They were using a variety of teaching techniques. One of them thought that the best way to learn physics was to learn to solve practical problems. The second one thought that the experiment was the basis of Physics. Only by doing experiments we will know what Physics mean. The third professor was a theorist. He had believed that it should start and end with the theory. The fourth one was a young teacher who did everything by the book without any changes or deviations.

Before the begging of studying they gave the Mechanics Diagnostic as a pretest to all the students, which showed the students that they had similar low scores. There was only a 15% improvement. After the course they made a final test. The average score was only about 60%. The average scores of all the classes were the same within 1% for all the professors. Based on these results, David Hestenes (Taşar et al., 2012) made seemingly unexpected conclusion: “So, student scores were independent of the professor’s experience, teaching technique, or whatever...” (p. 148).
Apparently, I believe that he is right, if the teacher uses only one of these teaching techniques. Modern technical facilities enable the students to use all these techniques for training in any place and at any convenient time. These are the networking opportunities that the Internet provides. In our opinion, with the above-mentioned teaching techniques of physics we should add one more: computer simulation of physical experiments.

Nowadays our students reject any information given on paper. It is the fact that we have to accept. And we have to make some conclusions for ourselves. Our students in their professional life will probably never work with paper documentation, the only tool for getting information and decision-making is a personal computer. The only real space where they want to be is the cyberspace. They are already internauts (the inhabitants of the Web). The only reasonable choice for us is moving teaching to the network, and we have to meet our students there.

One possibility is the use of the “Pull” technology (article “Physics learning instruments of XXI century” published in this book) in cognitive tests. As a result of passing cognitive tests the students are getting sufficient competences in decision-making on a wide range of physical problems. This goal involves ensuring access for students to organize content with special methods and to interactive decision-making tools, which can be evaluated in points.

Physics curriculum can be visualized on the basis of the five types of presentation physics content:

1. **Conceptual apparatus** is implemented in a verbal way in forms of definitions, rules, physical laws, which are generally accepted.

2. **Symbolic apparatus** (apparatus of symbolic links) of **formal relations** between physical parameters. This apparatus is in the form of a special code system as a combination of the universally recognized symbols linking isolated conceptual apparatus of the physical phenomenon.

3. **Apparatus of theoretical problems solutions** is formed on the basis of ownership of the **Apparatus of concepts** and **Symbolic apparatus of formal relations**. In this case for increase of the effectiveness and the visibility, they have to use elements of other code systems, such as graphs, charts, figures and tables.

4. **Apparatus of computer simulation** can represent models of physical phenomena. Modern technical facilities allow creation of dynamic models reasonably approximating the properties of the real physical phenomenon.

5. **Apparatus of real physical experiment** allows students to focus on the decision to set up for training purposes of the real situation, and a full cycle of scientific research, providing:
   - theoretical prognosis;
   - work with real physical objects and instruments;
   - processing of the experimental data with the use of modern software, evaluation of the results.

In our opinion, the physics skills training should be formed out in each of the directions separately because according to the laws of cognitive psychology “Competences are formed within the framework of activities that are directed to reach the goal”.

**Method**

In 1995 Malcolm Wells, Hestenes and Swackhamer (1995) proposed a new method of organizing the process of physics teaching. This method can be regarded as a way to teach systematic scientific inquiry. They coined the term “modeling cycle” for the integration of systematic modeling into the learning cycle. The central idea in the modeling approach is that you understand a phenomenon by creating or adapting a model to describe it. This method of teaching physics requires three successive stages:
• Representation of the system and its variables;
• Specifying relations among the variables and how they change;
• Validity of the model is established by comparing it with empirical data on how the system behaves.

The authors made this publication stating that such a learning algorithm enabled them to significantly improve the results of students.

In our point of view, the best way of learning is an active one. Using the Internet is by definition an interactive job. We used the idea of “modeling cycles” when we created physics cognitive tests. Based on the idea of modeling training cycles we combined in one educational tool, important and effective content (in our opinion), namely, that can be used in a global network. The result is a multimodal multitasking PC- and tablet-network oriented educational resource of physics learning designed to work in real time in platform MOODLE. Physical content thus organized and represented in a certain way is adapted to modern interactive communication technology equipment, in the form which we call “network modeling learning cycles.”

Introduced term reflects the peculiarities of design, visualization, and the use of training tools created. “Network” refers to a possibility of its use globally (wherever there is Internet access, including all the information resources it placed), and the activity of the trainees, as it suggests on their part of decision-making at every moment of the HCI (Human Computer Interaction). “Modeling cycle” means the use of both for the construction of the entire university physics course, and each task (or group of tasks) algorithm described above, including the possibility of

• providing structured content in a special way, sufficient for a complete description of the physical phenomenon;
• representation of the physical phenomena in the form of a complete dynamic model;
• the model established in the minds of students allows them to make decisions.

A substantial portion was created by us. We asked the authors of certain physical content lunched in the Russian segment of the Internet and obtained permission to use it. We created an educational resource designed for university students studying the course “General Physics” which has a complex multi-branched architecture. Conventionally it can be represented as a house of 5 - floors building with three entrances (on the French project). This building exists with opened doors and windows for students. We entitled it as “Global modeling cycle”.

Figure 2. Global modeling cycle.
Three entrances represent three semesters of teaching physics; we call them “Macromodeling cycles”. Each approach (semester) has five floors - “Minimodeling cycles”. This is due to the specifics of the educational process in high school (16 to 18 study weeks), so we use a step in three weeks. Each floor of this building represents its own name on the physics part of the semester. So in the first semester, we identified the following: “Kinematics”, “Dynamics”, “Work, energy and conservation laws”, “Molecular Physics”, “Thermodynamics”. Each floor is opened only for a specified time. However, at the end of the semester, during the last two weeks, for students who want to improve their results, we can open it again until the time of final testing. And most of the students use this opportunity. The “French Building” project means that it has a ground floor (rez-de-chaussée), and the first floor is actually the second. On this floor we placed the resources which students can download. There is a location for classic textbooks, problem books, reference books and videos. This floor is always open and you can always come back here.

Each floor has five apartments (“Micromodeling cycles”). These are teaching techniques and directions of formation of knowledge, skills and abilities. We list them:

- Concepts ("Physics knowledge check"). Cycles are based on the checking of theoretical knowledge (concepts).
- Formal links ("Physics formula check"). Cycles are based on the checking of knowledge of formulas.
- Solving ("Physics problems solution"). Cycles offer the solution to the problems of various complexities. To our mind, it is acceptable to take 40 tasks in 1.5 hours.
- Computer simulation ("Physics experiments simulation"). This cycle usually consists of 10 tasks with physics applets, seven of which are presented in English and three in Russian language.
- Physical experiment ("Physics experiment-making"). The last cycle is a full cycle of scientific research. The students do lab work at home without using any special physical equipment, but with modern computer tools.

The first modeling cycle we call "Introduction modeling cycle". It is needed to familiarize students with the ideology and characteristics of control tests. In this cycle, students can either read from the monitor screen or download to their computers specially prepared content ("Theory in detail", "Theory of short", presentations, lecture notes, list of formulas, patterns of problem solving and other reference material). At this level there is "Physics pre-test", which includes all tasks of microcycle “Physics knowledge check” randomly generated list of formulas (30%), as well as all types of task microcycle “Physics problems solution". Each apartment is filled with objects. These are the basic modeling cycles ("Elementary modeling cycle"), which may be one-bedroom “One-task elementary modeling cycle”) and multi-bedroom (“Multi-tasks elementary modeling cycle”).

**Data and findings**

We have created an educational resource that has a complex layered structure (currently only existing in the Russian version) and includes: more than 3000 original tasks; full university “General Physics” (in 3 parts); short course (as a reference); 48 thematic presentations; 45 presentations of lectures; lectures (in 8 parts); several hundred files containing additional information. The following figure presents real working panel in Russian with translation into English (on the right side).
In the first semester of teaching physics all starts with Minimodeling cycles “Kinematics”. The figure shows the working panel pretest (Micromodeling cycle) “Kinematics”. This test consists of the bank of tasks with 53 tasks on concepts and 40 tasks on formulas. The first type of micromodeling cycles introduces to the students the ideology and structure of the control tests. Our experience shows that 70% of students who scored more than 60 points had used it.

Tests can be represented by various means:

- Hypertext with graphics, charts and tables;
- Video demonstrations of physics processes and phenomena;
- Simulation of physics processes.

In our view, the cognitive test involves a special way of constructing tasks themselves as elementary modeling cycle. Each of these cycles include a complete listing of possible situations, which are necessary to describe the physical phenomenon. We separated cycles into One-task elementary modeling cycle and Multi-tasks elementary modeling cycle.

Three types of tasks are usually used:

1. Direct choice;
2. Logical choice;
3. Multiple choices;
4. Puzzle choice.

3.1 Direct choice

This type of task is based on the direct recognition of a physics object, for example, the choice of one object of 40 physics formulas located on one Web page.
Figure 4. The sample of tasks on Direct choice.

3.2 Logical choice

The second type of tasks proposes to finish the sentence with the true physics statement up to nine sentences adding to each other are given on one page. All sentences gathered together form a final idea of the physics process. For example task is started in figure 5. Usually students start to choose from the fact that they know for sure. For example, “write \( x = 0 \)” means that the body “is situated not far from zero.” Then, the “write \( x > 0 \)” means that the body is “body is situated to the right from zero.” ... And so on. In response to consistently and accurately known issues, students will be able to answer questions, the answers to which are not immediately apparent.

Figure 5. The sample one of tasks on Logical choice.

3.3 Multiple choice

The third type of tasks (Multiple choices) involves multiple answers in a single task. Below we show the screen shot of one of the tasks. It includes 9 simple graph-cycles in section Kinematics. In our view, an understanding of the charts is a special skill. That is why we give special attention to this. All cycles are deliberately based on the use of the same graphic pattern. We change conditions or names of axes. In this example, students should note several correct answers (there are 3 of 11).
Specify during which seconds the body moved uniformly backward.

**3.3 Puzzle choice**

In the last type of tasks (“Puzzle choice”) students are asked to assemble mental construction (maximum - 7 parts) with the given elements. The example is the following task, in which the answer to this question is a three-digit integer number, which is obtained by entering the serial number of the row of columns A, B and C. In this sample the correct answer is 321.

**Discussion and Conclusions**

The control tests are available to students from Friday evening till Monday morning. One of the most important points is the number of the attempts given to students for passing the tests. The minimum amount of the unique variants in each test formed from a random choice is not less than ten billion, so students can be offered any reasonable number of attempts. In our view, it is sufficient to give students 3 attempts.

We believe that it is not possible to create effective learning tools for students without the participation of students themselves. Teachers and students are representatives of different generations only aligned in time. Teachers have the knowledge and experience. Students perceive the world differently. Therefore, it is essential to combine in one resource the skills of teacher with feelings of students. In our group there
are 7 students which make the final decision on the design and content of each task. And authors of the present publication are two students.

For students cognitive tests are intellectual games, and the result is getting competences and score (in points) that can be improved by the further attempts. Cognitive technology can combine process of getting knowledge, skills and control. With such approach testing becomes a tool for learning physics. From our experience, students are ready, able and willing to work by the proposed algorithm.

By the cognitive tests, we understand the learning process in which we provide access for students to the content and decision-making tools. The offered content must be organized in a special way, and decision-making tools allow one to evaluate the results and progress of students.

Important outcomes

- Competences are formed within the framework of activities that are aimed at reaching the goal. Each way of representation and control of physical content should be separate in its modeling cycle.

- In learning process, students are allowed to make mistakes as many times as they like. Students should not be afraid of their mistakes and learn from them.

- Students should be able to improve and correct mistakes during learning process but only within a specified time interval. For this purpose it is necessary to provide for the possible existence of a large number of unique variants of tasks.

- Learning instruments are intellectual games, and the result is getting competences and real score (in points) that can be improved by further attempts. In our experience, students are ready, able and eager to be working according to the proposed algorithm.

References


Teaching and Learning Modern Physics Concepts to Primary Student Teachers

Dimitrios Stavrou, Department of Primary Education, University of Crete, Greece

Abstract

Relativity, quantum mechanics, nonlinear dynamics and recently also nanoscience count as significant scientific advances of the twentieth century physics (modern physics). Nevertheless science education research has shown that modern physics topics often get little attention in physics instruction in schools. School teachers’ missing knowledge is often named as a reason. This indicates that the integration of modern physics concepts into teacher training is important at teachers training both at the university level and in professional development courses for in-service teachers. The work presented here focuses on student teachers’ main difficulties in order to develop an understanding of modern science topics. It is based on four studies, using a teaching experiment design, with primary student teachers dealing with time dilation (relativity), the particle-wave duality (quantum mechanics), the limited predictability of deterministic chaotic systems (deterministic chaos) and size-dependent properties (nanoscience). The findings of the studies indicate that student teachers think in terms of “absoluteness” and “continuity” as well as that they utilize a “strict” causal view in interpreting the phenomena. These conceptions, which are based on the traditional teaching of classical physics in school, seem to hinder student teachers’ understanding of modern science concepts. A shift of science instruction towards a more relativistic and probabilistic view of interpreting the phenomena which highlights the limitations of Newtonian physics is suggested in order to facilitate subsequent learning of modern physics concepts.

Introduction

Relativity and quantum mechanics count undoubtedly as the most significant scientific advances of the 20th physics century. They marked a new era in science, as they gave rise to a new form of looking the world (Arriassecq & Greca 2012). Relativity suggests that the physical world is relativistic, since the measurements of time and space depend on the relative motion of the object and the observer. It challenges our expectations derived from experiences of everyday objects which normally move at speeds much below the speed of light. Nevertheless, relativity still leaves us with a deterministic view of the physical universe in which variables are related in such a way that a change of one variable produces a definite and predictable change in another dependent variable (Shabajee & Postlethwaite 2000). In contrast quantum mechanics sets the impossibility of precisely determining initial conditions (as, for example, position-momentum) and introduces the element of chance even in the behavior of an individual microparticle. Thus, quantum mechanics establishing and determining the limits of our feasible knowledge of nature, introduces the (partial) unpredictability in the physical world. Moreover the potentiality of two complementary descriptions of a physical system appears: the wave-like description corresponds to a holistic point of view and “observes” the collective properties that become nonobservable if we focus on the corpuscular ones (Kalkanis, Hadzidaki & Stavrou 2003).

Since the 1960s research on nonlinear systems has flourished considerably contributing to the development of the contemporary scientific worldview and stimulating discussions on the nature of science as well. An important class of systems described by nonlinear models are the deterministic chaotic systems (Schuster 1989). They show an irregular and complex behaviour based though on deterministic laws. The mathematical representations of these systems in a phase space show a characteristic structure that indicates a kind of order (e.g. chaotic attractors). In principle, the future development is completely determined by the past. However, in practice, due to their ‘sensitivity’ to small changes in the starting conditions and small disturbances when the process is running, the behaviour, even though it is predictable in the short term, it is unpredictable in the long term (limited predictability). In brief, deterministic chaotic systems show that the strict predictability of the systems’ behaviour is impossible despite the deterministic laws govern them. Therefore the interplay of deterministic laws and random deviations of the initial state as well as random disturbances plays a key role in explaining the ‘limited’ predictability of deterministic chaotic systems.
Recently the emerging fields of nanoscale and nanotechnology promise to have extensive implications for all of society as they apply the unique properties of matter at the nanoscale to create new products and technologies. The invention of scanning tunneling microscopy (STM) made it possible to develop a wide range of methods for investigating and controlling matter and its transformation at the atomic and molecular level (Euler 2012). The emergence of novel mechanical, optical, electric, magnetic, thermal, chemical and biological properties at the nanoscale as compared to bulk behavior seems to be a valuable general insight. For instance, colloidal suspensions of gold nanoparticles exhibit different colors at the nanoscale depending on particle size.

Nevertheless modern physics concepts are given little attention in school science curricula. Shabajee and Postlethwaite (2000; p. 51) argued for instance that “there is an urgent need to include the concepts of ‘twentieth-century physics’ within the curriculum”. Interestingly, science education research has recognized the potential of modern physics in science teaching. There is a growing body of science education research dealing with the basic ideas of modern physics from the fields of: i) relativity (e.g. Arriassecq & Greca, 2012; De Ambrosio & Levrini, 2010; Dimitriadi & Halkia 2012), ii) quantum mechanics (e.g. Johnston, Crawford & Fletcher 1998; Zollman, Rebello & Hogg 2001; Stefani & Tsaparlis 2009), iii) nonlinear systems (e.g. Duit, Komorek & Wilbers 1997; Laws 2004; Stavrou, Duit & Komorek 2008) and iv) nanoscience (e.g. Hingant & Albe 2010; Gardner et al 2010; Blonder & Sakhnini 2012;)

This research shows on the one hand, that the conceptual frameworks students develop during their traditional teaching of classical physics in school are responsible for severe difficulties when topics of modern physics are introduced (e.g. Fischler & Lichtfeldt 1992; Olsen 2002; Kalkanis, Hadzidakis & Stavrou 2003; Dimitriadi & Halkia 2012). On the other hand it shows that many of the teachers lack competence in teaching modern physics topics (e.g. Angell et al. 2004). As it is widely accepted that teachers’ quality is the most important factor influencing student achievement (Osborne & Dillon 2008) this lack of competence indicates that the integration of modern physics concepts into teacher training is important both at the university level and in professional development courses for in-service teachers.

Taking into account the aforementioned findings the work presented here focuses on teaching and learning modern physics concepts to primary student teachers. The work is based on four studies, each one covering a particular modern physics field, namely relativity (time dilation), quantum mechanics (particle-wave duality), nonlinear systems (limited predictability of deterministic chaotic systems) and nanoscience (size-dependent properties). The aim is to investigate primary student teachers’ main difficulties in order to develop an “appropriate” scientific understanding of modern physics topics. Hence, the main research question of the study presented here is:

- What are primary student teachers’ main difficulties in order to develop an understanding of modern science topics?

Method

The theoretical framework of the present work is the “Model of Educational Reconstruction’ (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012). The model has been developed as a theoretical framework for studies investigating whether it is worthwhile and possible to teach particular science concepts, principles and views of the nature of science. The major aim is to bring science content structure and educational concerns into a balance when developing teaching and learning sequences. The model consists of three closely interrelated components: a) Clarification and analysis of science content, including hermeneutical-analytical research on subject matter clarification and analysis of the educational significance of a particular science content. b) Research on teaching and learning, comprising investigations of students’ perspectives and their development towards the scientific view as well as studies on teachers’ views and beliefs of the science concepts, students’ learning and their role in initiating and supporting learning processes and c) Design and evaluation of teaching and learning environments, comprising the design of instructional materials, learning activities, and teaching and learning sequences.

The present work is based on four studies carried out with student teachers of the Department of Primary Education at the University of Athens and the University of Crete in Greece. These students have a good
background in pedagogical issues but a limited background in science and mathematics. After their graduation the students are going to teach in primary school (age 6-12) a wide range of subjects like greek language, mathematics, history. In the 5th and 6th grades they are required to teach science, an integrated subject with phenomena and basic concepts of the fields of physics, chemistry and biology.

In order to collect the data in the four studies the “teaching experiment” approach was applied (Komorek & Duit, 2004). Teaching experiments may be viewed as Piagetian critical interviews deliberately employed as teaching and learning situation. The ‘interviewer’ takes both the roles of a ‘classical’ interviewer, who attempts to understand students’ individual conceptions, and a teacher, who has to react to students’ conceptions and has to make the appropriate intervention just in the right moment.

In a small group setting of two students each, sixteen student teachers dealt with time dilation (relativity), fourteen with the particle-wave duality (quantum mechanics), eighteen with the limited predictability of deterministic chaotic systems (nonlinear systems) and twenty six with the size-dependent properties at the nanoscale (nanoscience). The author carried out the teaching experiments on the limited predictability of deterministic chaotic systems and on the size-dependent properties at the nanoscale. Under the supervision of the author the teaching experiment on the particle-wave duality was carried out by two M.Sc. students (Dodekatou, Ch. and Exarchakos, K.) in the frame of a course for M.Sc. students about Science Education and ICT. The teaching experiment on time dilation was carried out by a physics student (Kainadas, P.) in the frame of an undergraduate physics diplom thesis. The main phases of the teaching experiments are briefly the following:

**Time Dilation (Relativity):**
- Discussion about the concept of “time”
- Introduction of the invariance of the speed of light (2nd axiom)
- Exploration of the thought experiments “Einsteins’ train paradox” and “light clock” (Figure 1)
- Development of a representation about relativity of time

**Particle – Wave Duality (Quantum Mechanics).**
- Discussion about the motion of the electron in the Hydrogen atom and about the nature of the electron
- Discussion about diffraction and interference of mechanical waves
- Exploration of the build-up of an interference pattern of single electrons in the double-slit experiment (Figure 2)
- Development of a representation of the particle-wave duality

**Figure 2**: Double slit experiment: Electrons build over time (Hewitt 2002)

**Limited Predictability (Deterministic Chaotic Systems)**

Exploration of the chaotic pendulums’ behavior (see [http://www.pasco.com](http://www.pasco.com)) carrying out at first a *simple harmonic motion* and afterwards a *chaotic motion*.

Observation of the motion of the disk pendulum and of a real time plot regarding a) the angular position of the disk as a function of time \(\phi = \phi(t)\) and b) the angular velocity as a function of the displacement angle of the oscillation \(\omega = \omega(\phi)\) in a computer monitor (Figure 3). Attempts at identification of deterministic laws, order, predictability, chaos or chance.

Repetition of the experiments under the same/slightly different starting conditions. Comparison of the graphs \(\phi = \phi(t)\) and \(\omega = \omega(\phi)\) from the first and the second run of each experiment. Attempts at identification of deterministic laws, order, predictability, chaos or chance.

Development of a representation about the possibility to have deterministic laws without predictability.

**Size-Dependent Properties (Nanoscience)**

- Discussion about properties. Expectations and explanations of the behaviour of a steel nail, steel wire and steel wool after trying to burn them
- Expectations and explanations of the behaviour of a piece of potato and of small pieces of another potato after reacting with hydrogen peroxide (H2O2).

*WCPE 2012, Istanbul, Turkey*
Figure 4: The two substances are Cadmium Selenide. The only difference is the grain’s size (Halliday et al. 2001).
- Demonstration of a picture that exhibit the different colors of Cadmium Selenide grains (CdSe) at the nanoscale (Figure 4)
- Development of a representation of size dependent properties at the nanoscale.

The interviews were audiotaped and transcribed. Due to the explorative nature of the study, to analyze the data methods of qualitative content analysis were applied (Erickson 1998, Mayring 2000).

Data and Findings
The many detailed findings of the studies (see for example Stavrou et al. 2009; Stavrou & Euler 2012) are summarized in a set of “contradictions” presented in the following.

a) “Absolute vs. Relative”
Student-teachers tend to think in terms of “absoluteness”. They hold the idea that “physical objects and quantities have fixed characteristics”. For example in the teaching experiment about size-dependent properties as a discussion was triggered by the interviewer about the change of the colors of materials, most of them indicated that a material has a fixed color (usually the one that is visible in the sunlight). The change of colors is usually explained in terms of humans’ perception and not as a “real” change in the properties of the material that interact with the incoming light. In the same line students implied that time dilation has to do with observers’ perception, whereas the time the events happen is absolute. Changes are therefore assigned to humans’ limited capacities.

b) “Continuity vs. Discontinuity”
The student-teachers tend to explain the phenomena in terms of “continuity”. Most of them believe for example that properties remain invariant at all scales (e.g. molecules have smell) and they mainly interpret a physical behavior in an additive framework (e.g. the particle-wave duality of the electron is understood as a particle which makes a wave-like motion). However, the change of matters’ properties as we reach the nanoscale or the particle-wave duality concept causes difficulties as they have to think in the frame of quantum theory in order to give satisfying physical explanations of the phenomena. In other words, the transition from the experienced macroscopic world to the “extremely fast and extremely small” (Ariassecq & Greca, 2012) needs a thinking in terms of “discontinuity”, as different levels of physical theories have to be applied.

c) “Determinism vs. Indeterminism”
Student-teachers argumentation in explaining phenomena is based on a deterministic worldview. They interconnected on the one hand determinism – predictability and on the other chaos - chance – non-predictability. The main difficulties arise from the fact that these two groups of conceptions are considered
by the students as contradictory to each other (Stavrou et al. 2009). In the case of deterministic chaotic systems starting from a chaotic random behavior they have to indicate a deterministic behavior which is though unpredictable (arrows 1 and 2 in figure 5). This is not an easy task for the students as they have to make connections between two contradictory groups. In the same line the behavior of quantum objects is usually interpreted by means of the Newtonian/deterministic way of thinking. In the teaching experiment on particle wave duality they indicated for example a perceived absolute predictability concerning the electron positions in the double slit experiment.

Discussion and Conclusions

Science education research has shown that the conceptual frameworks students develop during traditional teaching of classical physics in school are responsible for severe difficulties when topics of modern physics are introduced. The findings of the present study provide evidence supporting this view. Thinking in terms of “absoluteness” and “continuity” as well as the utilization of a “strict” causal view in interpreting the phenomena is deeply rooted still in student-teachers. These conceptions seem to hinder student teachers’ understanding of modern science concepts. Therefore “by providing children with a ‘cognitive framework’, derived from Newtonian mechanics and presenting this both as unproblematic and all-powerful” (Shabajee, & Postlethwaite, 2000; p.52) has an impact on their subsequent learning of modern physics concepts. A shift of science instruction towards a more relativistic and probabilistic view of interpreting the phenomena, which highlights the limitations of Newtonian physics may result to more adequate conceptual frameworks for subsequent learning of modern physics concepts.

As the present study is explorative in nature, standard methods of interpreting qualitative data (like the qualitative content analysis) were used. Hence, the aim was not to test hypotheses but to develop preliminary hypotheses. Therefore additional research is needed to prove the findings for other samples.

References


WCPE 2012, Istanbul, Turkey


Design-Based Research for Teacher Professional Development Program on Scientific Argumentation

Junehee Yoo, Department of Physics Education, Seoul National University, Seoul, Republic of Korea
Heui Baik Kim, Department of Biology Education, Seoul National University, Seoul, Republic of Korea
Youngdal Cho, Department of Social Study Education, Seoul National University, Seoul, Republic of Korea
Seyoung Hwang, BK21 Science Education for Next Society, Seoul National University, Seoul, Republic of Korea
Jee Young Park, BK21 Science Education for Next Society, Seoul National University, Seoul, Republic of Korea
Eizo Ohno, Faculty of Education, Hokkaido University, Sapporo, Japan
Kazuyuki Asakawa, Faculty of Education, Hokkaido University, Sapporo, Japan
Dong Wook Lee, Department of Physics Education, Seoul National University, Seoul, Republic of Korea
Eun Hee Lim, Department of Physics Education, Seoul National University, Seoul, Republic of Korea

Abstract

The purpose of this study was to develop an effective professional development (PD) program focusing on scientific argumentation in ways that embody and refine theoretical assumptions underpinning a teacher’s reflective thinking and pedagogical content knowledge. The PD program development procedure was based on the methodology of design-based research, which develops and embodies design conjectures about a teacher’s professional learning. In Phase I, based on the literature review of scientific argumentation, embodied conjectures were conceived as principles for incorporating program activities and designs into the science teacher’s prior pedagogical content knowledge. Furthermore, a cultural comparative study of science teaching practice was conducted with the aim of understanding Japanese and Korean science teachers’ perception about the role of discussion in science learning. In Phase 2, that is the embodiment phase, a prototype of 15 hour PD program was designed and executed. Among various ‘outcomes’ which are produced in terms of teacher learning, in this paper, we focus on teachers gaining knowledge and skills related to scientific argumentation and forming some positive disposition towards implementation. Based on the embodiment and evidences, we propose refined design conjectures for teacher professional development focusing on scientific argumentation.

Introduction

Recently scientific argumentation has been regarded as a core activity in science learning (Jiménez-Aleixandre et al., 2000). Students’ engagement in collaborative discourse and argumentation offers a means of enhancing student conceptual understanding and scientific reasoning skills (de Vries et al., 2002; Driver et al., 2000; Osborne, 2010; Simon et al., 2006; Venville & Dawson, 2010). Especially on inquiry-focused science lessons, through stressing the process of constructing arguments as using their experimental data to link with a given scientific explanation in textbooks, it allows students to generate data, to carry out an experiment, to use data to answer a research question, and to write and be more reflective as they work (Sampson et al., 2011). In spite of its importance, however, it has been pointed out that argument and debate are not the main or natural parts of the ordinary science class (Forbes, & Davis, 2009; Sanders et al., 1994; Zembaul-Saul, 2009). For example, social interaction such as persuasion is not as much valued in school science as it is among real scientists (Kuhn & Reiser, 2009), and scientific explanation is not well integrated into students’ personal experiences, which formatively shape their epistemic beliefs (Sandoval & Cam, 2011).

Hence, it is now realized that the dominant classroom culture that dictates the teacher’s and students’ beliefs on science learning must be addressed in order to introduce successfully argumentation as the...
core activity in science learning (Duschl et al., 2007). Importantly, the teacher’s role as guide or facilitator is considered to be the key for guaranteeing effective communication between students during scientific argumentation (Brown & Palinscar, 1989). The teacher’s use of open-ended questions can play a crucial role in supporting students in argumentation and facilitating dialogic interactions between students (McNeil & Pimentel, 2010), however existing studies revealed that both pre-service and in-service teachers’ competence on scientific argumentation was not high, which suggests a need for providing professional development programs (Zembal-Saul et al., 2002; Yalcinoglu, 2007; Ozdem et al., 2011; Sampson & Blanchard, 2012). Furthermore, it has been acknowledged that teachers, even after participating in the professional development program, still had difficulties in applying their knowledge to practice (Simon et al., 2006; McNeill & Knight, 2011).

Although an increasing effort has been made to develop a teacher professional development program focusing on scientific argumentation, little has been discussed about design principles and the teacher learning environment necessary, particularly intending to facilitate teacher’s professional learning on scientific argumentation. Therefore the purpose of this study was to develop an effective professional development (PD) program focusing on scientific argumentation in ways that embody and refine theoretical assumptions underpinning teacher’s reflective thinking and pedagogical content knowledge. The PD program development procedure was based on the methodology of design-based research, which develops and embodies design conjectures about teachers’ professional learning.

The PD program development procedure was based on the methodology of design-based research, which develops and embodies design conjectures about teachers’ professional learning.

The structure of the paper is as follows: First of all, we describe a rationale for the PD program focusing on scientific argumentation in terms of three distinct phases based on a design-based research method - derivation, embodiment and refinement of the conjectures. Next, sections are written, focusing on each phase. In Phase I - Derivation of the Conjecture - we focus on the teacher learning environment during the PD program by especially addressing a teacher’s pedagogical content knowledge. The theoretical conjecture is then further elaborated upon through an empirical analysis of a teacher’s perception of their own science teaching practice. In Phase 2 - Embodiment - the content of the actual PD program is briefly introduced focusing on how design conjectures were embodied. Also, expected outcomes by embodying the conjectures and the empirical result accordingly are analyzed with a focus on the teacher's knowledge and skills related to scientific argumentation and their disposition towards implementation. Finally, ways of refining the conjectures and issues remaining are considered.

**Design-based research methodology for teacher professional development on scientific argumentation**

Design-based research is a methodology that focuses on producing instructional intervention and a supportive learning environment (Collins, 1999). Its strength lies in advancing theories of learning throughout the design process, therefore, it is congruent with the aim of the current study concerning theoretically-oriented teacher professional development specifically focused on scientific argumentation. Sandoval (2004, p.215) defines design-based research in terms of a systematic study of designed interventions by using the term ‘embodied conjectures’ as the core concept, meaning ways of supporting learning in a specific context that are themselves derived from learning theories. In our PD program case, based on the literature review of scientific argumentation, embodied conjectures were conceived as principles for incorporating program activities and designs with the science teacher’s prior pedagogical content knowledge. Figure 1 shows the procedure of our design-based research of teacher professional development on scientific argumentation. Throughout Phases 1-3, theoretical and analytical foci rested on how to support a teacher’s active reflection on their teaching practice and how to support their learning regarding the knowledge and skills that are necessary to become positively disposed towards introducing argumentation activities into their teaching practice. During the execution of the PD program that is the embodiment phase, it was predicted that various ‘outcomes’ would be produced in terms of teacher learning, among which, in this paper, we focus on teachers gaining knowledge and skills related to scientific argumentation and forming some positive disposition towards implementation. In this respect, caution should be taken not to conflate outcomes with effects of the program: that is, the outcome is considered to be empirical evidence of the design conjectures, which then need to be refined. In the following sections, we describe each phase in detail.
Figure 1. The procedure of design-based research for teacher professional development on scientific argumentation

Phase 1: Derivation of the conjectures

1) Theoretical framework of science teacher pedagogical content knowledge

As addressed in McNeill & Knight (2011), it is necessary to provide professional development experiences in ways that integrate and even challenge a teacher’s own pre-existing pedagogical content knowledge (PCK). Following Magnusson et al.’s (1999) framework, we identified PCK components that can be suggestive of defining the teachers who are willing to introduce argumentation-based science teaching (Fig. 2). The assumption is that although the term ‘scientific argumentation’ is not familiar to science teachers, a teacher’s disposition towards using discussion or debate indicates his or her awareness of science learning that focuses on evidence-based communication.

In terms of design conjecture, the PCK framework provided a rationale of the PD program: a key to teacher learning is to facilitate teachers’ reflection on their current PCK (particularly with respect to the ones shown in Figure 2), and to integrate new knowledge and beliefs about scientific argumentation into this existing knowledge base.

A. Orientations to teaching science
   - the goals and the nature of instruction
   Teacher’s experience of using discussion/preferences

B. Beliefs about the nature of science and learning science
   Reasons why discussion is necessary

C. Beliefs about self and learners
   Confidence in using discussion

D. Knowledge of science curricula
   How discussion relates to inquiry, scientific attitude, communication

E. Knowledge of students’ understanding of science
   Discussion is useful to develop students’ cognitive process

F. Knowledge of instructional strategies
   How to promote students’ discussion

G. Knowledge of assessment of scientific literacy
   How to evaluate the quality of discussion

Figure 2. Theoretical framework and examples of survey items for science teachers’ pedagogical content knowledge (based on Magnusson, et al., 1999)
2) Understanding current science teaching practice: An interview study

Since our design should be derived in ways that address the gaps between science teachers’ current knowledge and practice and the required knowledge and skills for scientific argumentation, we conducted an interview study to survey the former. At this point, since the term ‘argumentation’ was not familiar to science teachers, everyday words, such as ‘discussion’ or ‘debate’ were used in association with evidence-based or reasoning in order to capture teacher’s current knowledge and practice in a broad fashion. The survey items were derived from the categories of PCK as shown in Figure 2. The results were then used in developing the conjectures, especially for teachers to develop their instructional environment in ways which promote students’ active participation in argumentation activities. The survey items were also used on the first day of the program in order to facilitate the teacher’s own reflection on his/her teaching practice throughout his/her professional development experience.

**Aims and implementation of using discussion**

The participants from both countries seemed to be aware of the need for, and the aims of, argumentation, in that it can be helpful for students to share their ideas, understand scientific concept more easily, improve critical thinking and reasoning, and promote communication skills. However, actual implementation is not active and depends highly on a teacher’s personal disposition.

**Teachers’ difficulty in and strategy for promoting student discussion**

The participants from both countries revealed various difficulties in promoting student discussion describing their experiences on argumentation instruction. There seemed to be three kinds of obstacle; the first one is their low confidence with regard to instructing argumentation lessons. They had limited experience of argumentation from school days as well as during teacher training courses. More practically, the second obstacle is pressure for teachers to make sure that everything in the textbook is covered and for pupils to get prepared for their examinations. In addition, it required a greater amount of teacher preparation than the traditional way of instruction. The third obstacle is that even though the teacher tried to achieve argumentation in the science lesson, students are mainly too shy and passive to engage in classroom debate. They tend to follow what the high achievers say, rather than try to argue from their own viewpoints. Teachers from both countries stressed the need to understand individual students’ dispositions and learning attitudes during classroom or group discussion, e.g. instructional strategy for stimulating the participation of quiet students.

**Evaluation of students’ science learning during discussion**

It was evident that since the participants’ own experience on argumentation instruction itself was limited, their knowledge on evaluating students’ science learning through argumentation was also limited. However, teachers were united in saying that assessing students’ scientific discourse was challenging due to the issue of objectivity not being easily resolved. Hence in the actual inquiry activities, students’ reports were often omitted from formal assessment or the part on reasoning based on the experimental data and associated theory, which was beyond subjectivity, was included alone.

3) Design conjectures

The purpose of the PD program is to enhance teachers’ disposition toward introducing argumentation-based science teaching by experiencing that the inquiry-based argumentation activity are effective in cognitive as well as highly engaged. To address this purpose, we derived design conjectures from four perspectives of learning: content, topic, strategy and support environment.

Based on the understanding about the current science teaching practice from the teachers’ viewpoints, design conjectures were derived with a focus on ways of developing teachers’ knowledge and skills about scientific argumentation. Also, based on the literature review of PD program studies, teachers’ lack of experience in

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1 The interviews were conducted with fifteen Japanese teachers and thirteen Korean teachers as part of a larger project. In this section, the analysis focuses on a “shared repertoire” for understanding science teaching in the two countries (Troman & Jeffrey, 2007) by addressing current issues expressed from the teachers’ point of view (cf. Lyons, 2006).
scientific inquiry and scientific argumentation was one of the obstacles that hinders a teacher’s competency; therefore, design conjecture in our program should include provision of such experiences. Teacher activities were presumably experienced within a highly supportive instructional environment in ways that increase a teacher’s awareness of such an environment as being necessary for their own teaching practice. The conjectures regarding the teacher learning environment were derived from the literature on project-based learning environments (McNeil et al., 2006). The tentative conjectures are as follows.

- **Conjecture 1.** The argumentation tasks should motivate teachers to argument by meeting qualifications as follows.
  - debatable and cognitive conflict inducible: The inquiry results or data can’t be explained directly by theory or well-known explaining models. The level of cognitive challenge in task should be optimized for teachers’ subject content knowledge, meanwhile it must evoke teachers’ cognitive conflicts to make them engage in argumentation.
  - Contextualized: The topics which many teachers could have experiences and feel difficulties in teaching should be selected to make the task be more relevant to teachers.

- **Conjecture 2.** The structure of inquiry-based argumentation tasks enhance teacher’ argumentation by embodying the following concrete strategies.
  - concrete aims or final deliverables
  - P.O.E.(Prediction-Observation-Explanation): P.O.E. should be included in each step of inquiry in order to engage teachers in the scientific reasoning process and evidence-based communication.
  - first clarifying individual thoughts and then argument for social construction: For an active social construction, teachers were guided to write their own thoughts first, and then share and discuss these within a group. In this way, every teacher was encouraged to clarify their ideas and make efforts to reach a conclusion based on argumentation.
  - supportive materials which includes alternative claims or explanation models for scaffolding

- **Conjecture 3.** Highly supportive instructional environment should be provided through
  - easy access to the facilities and information
  - instructors’ role as guide or facilitator:, instructor’s quick understanding in group members problem and on-time feedback

- **Conjecture 4.** Explicit knowledge about argumentation is necessary, because the survey results show that teachers have narrow conception and use of discussion (e.g. mainly confined to the instrument for conceptual learning).

The following shows how these conjectures were embodied into inquiry activities and throughout the PD program.

**Phase 2-1: Embodying the conjecture**

1) Inquiry-based argumentation activities

During the program, each teacher was to select two out of four inquiry tasks: photosynthesis, color perception, Charles’ Law, and whirling tornadoes in a sink (See Table 1.). All topics were closely related to the scientific concepts required by the national science curriculum. The common principle in choosing inquiry topics was to evoke cognitive conflict according to Conjecture 1. For example, the interpretation of experimental data was not straightforward because the experiment procedure itself was problematic therefore needs to be re-designed, or there can be alternative explanation models. And then, four inquiry activities were formatted by embodying Conjectures 2 and 3.
Table 1. Summary of inquiry activities

<table>
<thead>
<tr>
<th>Topic</th>
<th>Task summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis and wavelength of light</td>
<td>‘Plant factory’ has plans to develop a device to help plants grow in the Antarctic. As an expert, you are asked to give them advice on what is the best light wavelength for photosynthesis to occur efficiently. Your purpose is to determine and persuade adoption of whichever is the best light wavelength supported with experimental result.</td>
</tr>
<tr>
<td>Color perception</td>
<td>Construct your own explanation model of color perception after a series of experiments and answering questions such as “When people perceive colors of two lights are same, should spectrums of two light be the same?” “Why the three primary colors are red, green and blue?” and so on.</td>
</tr>
<tr>
<td>Charles’s Law</td>
<td>Experimental set up of Charles’s Law in some text book may induce non-linearity of results. Figure out which part of the given experiment set up would be causes of non-linearity of the result, and suggest the way of improvement of the experiment set up.</td>
</tr>
<tr>
<td>Whirling tornadoes in a sink</td>
<td>After watching a couple of video clips of whirling tornadoes in Ecuador, one student is asking whether whirling tornadoes in a sink are due to the Earth’s rotation. As a science teacher what could be your answer? And how can you support your answer?</td>
</tr>
</tbody>
</table>

Subsequently, three or four teacher volunteers participated in the pilot test of each activity. They completed a task in a small group setting, and feedback was gathered concerning whether the inquiry procedure, as well as the topic, was designed well enough to provoke teachers’ interest and cognitive conflict. Importantly, an issue was raised concerning the fact that many teachers were unfamiliar with solving open-ended inquiry tasks or arguing with each other. It was dealt with by devising an explicit guide in each phase of the program in ways that facilitate teachers to think reflectively on their current teaching practice and to develop a positive disposition towards considering scientific argumentation as their new teaching strategy. The example of such a guide is as shown in Table 2.

2) An example of inquiry-based argumentation activity: Color perception

Color perception is a novel subject in the Korean national curriculum. In the current curriculum, students learn primary colors and color mixing in the 8th grade; then they study color perception and the principles of digital color media, including that of LCD TV and digital cameras. However, only part of this theme was included in pre-service teaching curriculum and many science teachers have fragmented knowledge when it comes to understanding color perception in physics and biology. In addition, it is not usual to draw cognitive conflict about color perception in everyday context, because color perception is an inherent ability of one of the senses. So, teachers could be motivated strongly when I were induced in some discrepant events. It is the rationale for choosing the topic according to the conjecture 1.

Flows of Fig. 3 were carefully constructed in order to drive teachers into argumentation according to the conjecture 2. First of all, we raised driving questions at each step of the flow. Discrepant events of metamerism experiments were prepared to incite conflict. Metamerism occurs when different combinations of light across all wavelengths can produce an equivalent receptor response, which leads to same color sensation. We prepared two same amber color lights, which have different spectral distributions (Fig. 4). Teachers were asked to predict and explain what happened on two amber color lights. One was single amber LED, which has a single peak around 580, another one had the same amber color by mixing red and green LED, which have a double peak around 510 and 625. Before and after observation of wavelength distribution of the two same amber colored lights, teachers explained what had happened using their model of color perception. After the first activity of explaining amber lights, they discussed magenta and yellow cases to check their own model’s adoptability. To help construction of scientific model to explain color perception, we engaged them into several stages of argumentation providing supportive materials and personal review before discussion.
Table 2. Examples of explicit guides in the photosynthesis activity

<table>
<thead>
<tr>
<th>Teacher’s tasks</th>
<th>Instructor’s tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To imagine a scientist’s diet at the South Pole</td>
<td>• To engage teachers in the task</td>
</tr>
<tr>
<td>• To recall the factors that increase photosynthesis</td>
<td>• To pose the question: How can plants’ photosynthesis rate increase in relation to the color of light?</td>
</tr>
<tr>
<td>• To build a group hypothesis with given ‘information bank’ sheets (inherently the problem cannot be solved with the existing limited information)</td>
<td>• To provide an encouraging environment</td>
</tr>
<tr>
<td>• To design an experiment and carry out the experiment to test the hypothesis</td>
<td>• To encourage teachers to talk in a group</td>
</tr>
<tr>
<td>• To criticize their hypothesis or to discuss reasons for errors in experimental results</td>
<td>• To guide the use of experimental materials</td>
</tr>
<tr>
<td>• (Reference: New ‘information bank’ sheets, which show experimental errors and consider other related factors)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4. Experiment used in activity 1-2 and 1-3: Two amber color lights (left), the left one is single amber LED, and the right one is green & red LEDs in lighting (right).

In the first argumentation of the amber lights explanation, we provided supportive material, which contains four explanations of exemplary models. We found that teachers had two types of exemplary models through previous study and pilot tests. The first type is based on wave modulation concept rooted in physics knowledge, known as alternative concept. In wave modulation concept, teachers explain that mixed colors appear as amber by changing the wavelength of lighting. We found three variations of exemplary model for the wave modulation type. The first one was the wavelengths of two peaks were averaged, the second one was the two wave were superposed, and the third one was the two frequencies were averaged (Fig. 5). All these explanation models are rooted in physics concept. The second type is cones excitation model supported by knowledge of biology, which is a scientific concept of color perception. Two lights appeared as the same amber lights because it stimulated two cones of green and red regardless of the numbers of peaks.

![Wave Modulation Models](image)

- **Wavelength Averaged (W.A.)**
- **Wavelength Superposed (W.S.)**
- **Frequency Averaged (F.A.)**
- **Cones Excited (C.E.)**

Figure 5. Alternative models of amber lights shown in the supportive materials

3) The PD program on scientific argumentation

The actual program was designed through embodying the conjectures. The content of the PD program...
is as shown in Table 3. The program ran in June 2012 in collaboration with the Department of In-service Training, Seoul Science Park and Seoul Metropolitan Office of Education. Although still occurring during the school semester, eighteen passionate teachers volunteered to participate in a four-day intensive workshop. Teacher profiles are summarized in Table 4. Each day comprised of four hours of lectures and/or activities, which are related to the specific content of conjectures.

On the first day, teachers were introduced to the rationales and theories of scientific argumentation-based instruction according to the conjecture 4. The traditional type of lecture was complemented by an ensuing small-group discussion on their practice and the potential implications of scientific argumentation as an innovative strategy. These were intended to evoke teacher’s reflection on their current science teaching practice in view of argumentation-based instruction. Between lectures teachers also responded to surveys used in teacher perception studies above, in order to aid such reflective thinking.

On the second and third days, teachers were fully engaged with two inquiry tasks chosen by them. We encouraged teachers to “take off an educator’s hat and put on an enquirer’s hat”, with the aim of inviting them to get immersed in the cognitive process as their students would do. This was followed by a session, putting their educator’s hat back on to facilitate teachers to consider whether the same task can be used in their teaching, and if so, what issues should be addressed. The last day was then fully devoted to the design of science lessons that introduce scientific argumentation as the central part of the students’ learning process. Within the same small groups teachers began to collect their personal and collective thoughts that occurred throughout the workshops. Each group was able to come up with an inquiry topic, which had not been introduced during the workshop. The day concluded with a group presentation session during which participant teachers’ positive disposition to adopt an argumentation-based instructional strategy was presented, albeit tentatively.

Table 3. The outline of the developed PD Program

<table>
<thead>
<tr>
<th>Day</th>
<th>Lesson 1 (50 mins)</th>
<th>Lesson 2 (50 mins)</th>
<th>Lesson 3 (50 mins)</th>
<th>Lesson 4 (50 mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>Introduction</td>
<td>Lecture 1: Scientific argumentation</td>
<td>Lecture 2: Instructional environment for argumentation</td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>Small Group Activity 1-1: Photosynthesis and wave length of light or whirling tornadoes in overflow</td>
<td></td>
<td>Small Group Activity 1-2: Reflection</td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td>Small Group Activity 2-1: Color perceptions or Charles’ Law</td>
<td></td>
<td>Small Group Activity 2-2: Reflection</td>
<td></td>
</tr>
<tr>
<td>4th</td>
<td>Small Group Activity 3: Designing lesson plan</td>
<td>Presentation</td>
<td>Discussion and closing</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Participants of PD program

<table>
<thead>
<tr>
<th>Number of participants</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major</td>
<td>Physics: 7, Chemistry: 4, Biology: 5, Earth Science: 2</td>
</tr>
<tr>
<td>Schools</td>
<td>Junior high: 5, Senior high: 13</td>
</tr>
<tr>
<td>Teaching experience</td>
<td>0-5 years: 5, 5-10 years: 4, more than 10 years: 9</td>
</tr>
<tr>
<td>Gender</td>
<td>Male: 4, Female: 14</td>
</tr>
</tbody>
</table>
Phase 2-2: Outcomes

The outcomes of embodied conjecture in this design research were specified in terms of teachers gaining knowledge and skills related to scientific argumentation and forming some positive disposition towards implementation. The first part of this section takes account of some evidence on four of the participating teachers’ knowledge about scientific argumentation as gathered through writing and activity sheets, and observation, and is followed by teachers’ argumentation skills in the case of physics inquiry activity. Finally, teachers’ disposition towards introducing scientific argumentation into their teaching practice is reported with the same four teachers’ cases.

1) Teachers’ knowledge about scientific argumentation

The teachers’ knowledge about scientific argumentation was examined in the light of their acquisition of the structure of argumentation, especially TAP (Toulmin’s Argumentation Pattern; Toulmin, 1958). The participants examined three argumentation tasks including student-student argumentation, teacher-students classroom argumentation and students’ written argumentation. Each task sheet has a blank TAP diagram in which the claim was given while the others, such as data, rebuttals, warrants, and backing were not provided. Table 5 shows the four teachers’ ability to identify TAP measured before and after the lecture about scientific knowledge on the first day. Overall, they were able to identify more argumentation terms, as well as understand the role of each argumentation term, through the PD program. Furthermore, they were well aware of the importance of various grounds for more developed argumentation, and identified rebuttals easily. No teacher, however, was able to identify all argumentation terms correctly, and misunderstanding persists in distinguishing backing from warrants. Also, their capability depended on the type of task.

In spite of such conceptual difficulty, the teachers recognized that analyzing students’ argumentation into the five argumentative elements can be useful not only to assess the level of students’ argumentation but also to discover reasons for the low level of students’ argumentation. Also, importantly, they began to note the importance of showing ‘rebuttals’ or ‘counter-argumentation’ in making argumentation more appropriate and persuasive. This suggests that participants have clearly recognized the nature of argumentation, its structure and the critical features of quality argumentation, such as counter-evidence and counter-claim.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>S-S task</th>
<th>T-S task</th>
<th>Written task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pre</td>
<td>post</td>
<td>pre</td>
</tr>
<tr>
<td>James</td>
<td>CDWBR</td>
<td>CDWBR</td>
<td>CDWBR</td>
</tr>
<tr>
<td>Cathy</td>
<td>CDWBR</td>
<td>CDWBR</td>
<td>-</td>
</tr>
<tr>
<td>Yuna</td>
<td>CDWBR</td>
<td>CDWBR</td>
<td>-</td>
</tr>
<tr>
<td>Jane</td>
<td>-</td>
<td>CDWBR</td>
<td>CW</td>
</tr>
</tbody>
</table>

(S-S task = student-student argumentation task, T-S task = teacher-students argumentation task, Written = students’ written argumentation task; C = claim, D = data, W = warrants, B = backing, and R = rebuttals; the middle bar represents filling out the blank TAP diagram with misunderstanding of each argumentation term).

2) The teachers’ engagement and progresses in explanatory models during inquiry activities

The teachers’ explanatory model of color perception could be categorized by two groups. As explained in an earlier chapter, one is wave modulation model based on physics, another is cones excitation model based on biology. Even though teachers had already learned seeing colors as perceived by cones, some teachers tried to explain amber lights by wave modulation model. Their models had been altered when discrepant events arose and driving questions were raised. It was helpful for revealing the teachers’ color perception model and evoking argumentation. Table 6 shows an example of how the teachers changed
their model by events. Many teachers tended to match colors with wavelength distribution and have the belief of existential color not as a perceived one. Sue and Jean majored in biology, whereas Betty majored in physics in college. They all answered that we have three cones in our eyes in response to a question asking why there are three primary colors. However, their explanations were different to the metamerism experiment. Sue and Betty explained it as wavelength superposed and frequency averaged. After using a spectrometer for checking wavelength distribution, they were not aware that wavelength had not changed in a cup, which had green and red LEDs. The magenta case helped them to adopt their scientific model of cones excited. However, it was resisted; Betty retrieved her alternative concept and Sue suggested another model of wavelength dependent cones excited, which was a compromised model of cones excited and wavelength dependent in next yellow case.

Table 6. An example of teachers’ color perception model alteration

<table>
<thead>
<tr>
<th>Participants</th>
<th>Pre-knowledge</th>
<th>Metamerism experiment (amber)</th>
<th>Magenta case</th>
<th>Yellow and other case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sue (biology)</td>
<td>Cones</td>
<td>Wavelength superposed, frequency averaged</td>
<td>Cones excited</td>
<td>Wavelength dependent cones excited</td>
</tr>
<tr>
<td>Betty (physics)</td>
<td>Cones</td>
<td>Wavelength superposed, frequency averaged</td>
<td>Frequency averaged, cones excited (weak)</td>
<td>Frequency averaged,</td>
</tr>
<tr>
<td>Jean (biology)</td>
<td>Cones excited (weak)</td>
<td>Cones excited (strong)</td>
<td>Cones excited</td>
<td></td>
</tr>
</tbody>
</table>

Argumentation of color perception revealed and reconstructed teachers’ models of color perception; even though their argumentation was not well-developed. They could adopt their model in cases of discrepant event; their following vignette describing teachers’ belief of existential color was resistant to understanding perceived colors.

3) The teachers’ disposition towards introducing argumentation activities

The evaluative survey was performed after the PD program. All participants except one responded the inquiry-based argumentation activities were very good or good. The most popular reason for positive response was they could learn something they had not known yet. Also 4 participants among 18 participants were willing to introduce argumentation based learning to their own classes.

We analyzed the reports of four participants with positive disposition. It is noticeable that all of them have recognized the importance of argumentation and interactive classroom discussion in more general terms. However, a more concerned voice was evident in terms of the actual implementation in ordinary science classes. The teachers had rarely used argumentation or interactive strategies, mainly due to concerns about the class becoming messy and out of the teacher’s control, the mandate to cover the national curriculum contents and the low engagement of students. However, their positive feedback was received, especially regarding their hands-on inquiry experience, in designing lesson plans. Particularly, teachers found well-guided teaching materials, additional information source, and equipment for lab activities were very helpful. Meanwhile, the examples of specific teaching strategies introduced during the lecture were considered to be fruitfully used to build students’ conceptual development. Also, the series of instructional steps and guides (as shown in 4-1 and Table 2) might be very useful to integrate students’ prior knowledge into a new claim.

During the lesson planning session, the teachers shared their own practical tips for creating a more interactive and supportive environment, including group-making strategies by considering individual students’ personalities and learning styles, and creating interaction and learning in progress during the waiting time. Yet the teachers felt the inquiry experience itself was not sufficient to make them prepared to implement those activities in their classrooms, and more practical support, including a further PD program, teaching materials and many exemplary lessons needed to be developed.
Conclusion

When we revisit the four tentative conjectures by considering related outcomes, we could argue that the four tentative conjectures are acceptable. But more subtle refinements are needed for embodiments of conjectures, especially conjecture 4 (explicit knowledge of argumentation).

References


A Developed Teaching Model for Metacognitive Thinking: Developed Metacognitive Learning Cycle

Eman Mohammad Alrwaythi, Imam Mohammad University, College of Social Sciences, Riyadh, Saudi Arabia Email: dr.emanaa@gmail.com

Abstract

Learning science is sometime difficult for students, particularly when they conduct a specific learning task, such as an experiment or mathematical problem. They often face problems of lacking the plan on which they can rely on and help them connect between the goals of learning tasks and the process to execute these tasks and the outcomes of these tasks. In addition, students are unable to express their scientific thoughts and articulate them in a good scientific manner, let alone their ineffective participation in learning. Education research have, in recent years, focused on metacognitive thinking strategies to help learners establish attentive control over their thinking and action and help them organize their planning and learning process of the learning tasks. This study proposed a developed teaching model of the Metacognitive Learning Cycle (MLC), which was developed by Lisa Planck in 2000. It aimed at investigating the effectiveness of the Developed Metacognitive Learning Cycle Model in developing grade 11 Saudi Female students’ conceptual understanding of physics and their metacognitive thinking skills. A priori-performance of a research group was measured using three tools: Conceptual Understanding test, Self-assessment scale to measure students’ awareness of their ability to use the three metacognitive thinking skills (planning, monitoring and controlling and assessing) and an observation sheet to measure how students practice the three metacognitive thinking skills in the practical activity. The research findings have shown that there is a statistically significant difference (at level ≤ 0.05) between the post average scores of the experimental group students (taught according to the Developed Metacognitive Learning cycle Model) as well as the control group students (taught in the traditional way) in the total conceptual understanding test. To assess the effectiveness of the Developed Metacognitive Learning Cycle Model in the total conceptual understanding test, the ETA-square (\(\eta^2\)) was calculated; reaching the value of (86%) in the total test. This percentage is of great influence; indicating the effectiveness of the Developed Metacognitive Learning Cycle Model in developing grade 11 female students’ conceptual understanding.

Introduction

The main objective of teaching is to help people develop this ability to do new things; not simply repeat what previous generations did. In the Arab world, however, teaching mostly focuses on having the students cram a lot of information so they can achieve good marks. In addition, most courses are organized based on a content that must be covered and taught, which led student-learning focus mainly on understanding what is superficial and not what is profound. The problem becomes more serious in the light of superficial assessment and current testing.

In this respect, this study proposes a developed teaching model for the Metacognitive Learning Cycle (MLC), which was first introduced by Lisa Blank (Blank, 2000), using the traditional learning cycle. The author of this study developed this teaching model in a way, through which science ideas, science expertise and science understanding can be strengthened. This helps in developing understanding with all its aspects as well as developing metacognitive thinking skills.

The development of the Metacognitive Learning Cycle Model included the integration of metacognitive teaching practices (the 13 strategies). These strategies are: reflection according to the plan, identification and clarification of the terminology students use, reformulation of ideas, learning logs, use of multi-criteria assessment, appreciation, teacher as a model, concept maps, self-inquiries, labeling students’ behavior with scientific terms, considering the phrase “I cannot” unacceptable in the classroom, conscious and intentional selection and role-playing with the MLC. In addition to the new and final stage Post Concept Assessment, through which students assess what is learnt and how. Also, the use of multiple methods of...
assessment, which helps emphasize learning and encourages reflection. Thus, the MLC model, developed by the author in this research, includes 5 stages: assessing knowledge and concepts before learning (Prior Concept Assessment); exploring the concepts to be taught according to a specific plan and through self-inquiries (Concept Exploration); after that, introducing acquired concepts through debates and discussions (Concept Introduction); then implementing these concepts in new areas (Concept Application); and finally, assessing the acquired concepts after learning (Post Concept Assessment), through reflection on the concept taught and the way it was learnt, (Figure 1).

![Image of the five stages of MLC model](image_url)

**Figure 1.** The five stages of MLC model.

**Description of the learning stages of the developed teaching model for metacognitive thinking:**

As indicated above, the developed MLC Model consists of five stages, which are: prior concept assessment, concept exploration, concept introduction, concept application, and post Concept Assessment. This developed model is designed to train the learner how to plan, implement, and assess practical activities (metacognitive thinking skills). It also helps the learner understand the scientific material presented in the lesson so that student can explain, interpret, apply what he is learning, have a perspective on what is learnt, empathize with others, and understand himself. Therefore, the Conceptual Framework\(^1\) of the developed MLC Model is based on three theoretical perspectives:

- the theoretical assumptions of constructivism; represented by Piaget’s theory (Cognitive Constructivism), Vygotsky’s theory (Social Constructivism) and Ozbul’s theory.
- Key principles to teaching according metacognitive thinking strategies.
- Teaching principles for understanding.

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\(^1\) Conceptual Framework is the theoretical guidance given to the practical study, in light of the general theoretical framework, in which ideas and principles strongly related to the subject matter are derived and are presented as conceptual guides that help demonstrate how the Metacognitive Learning Cycle Model is developed.

*WCPE 2012, Istanbul, Turkey*
Table 1. the theoretical bases and main principles underlying each stage of the Developed Metacognitive Learning cycle:

<table>
<thead>
<tr>
<th>Theoretical Bases, Principles, and Ideas</th>
<th>The Stages of the Developed Metacognitive Learning Cycle as an Application of Those Theoretical Bases and Principles</th>
</tr>
</thead>
</table>
| - Ozbul’s theory: “the learner’s prior information is an important factor in determining what the individual learns in a given situation” (Alkhaleely, 1996) | Stage One – Prior Concept Assessment:  
This stage focuses on assessing the state or prior knowledge of the concept in order to rectify or modify any misconceptions related to the concept to be taught. The following teaching methods are used at this stage:  
- Concept maps  
- Methods to detect misconceptions  
- Henes’ self-inquiries  
- Methods to modify misconceptions |
| - Metacognitive thinking principles: learning new materials should be linked to the learner’s prior knowledge and prior concepts (Jaber, 1999). | |
| - Teaching principles of understanding: deep understanding helps the teacher reveal misconceptions students have and make a conceptual change in these areas (Zaitoon, 2004). | |
| - The Assumptions of Constructivism:  
A. “The learner creates meaning of what he learns on his own as the meaning is formed in his structure of knowledge through the interaction of his abstract senses and the world” (Sabry & Tajudeen, 2000).  
B. “Learning is a process that is constructive, active, stable, and objectively oriented” (Zaitoon, 2003).  
C. “It is good to place the learner, whenever possible, in a situation where he faces a problem that challenges his thinking reasonably and motivates him to search for a solution using educational materials” (Zaitoon, 1982). | Stage Two – Concept Exploration:  
This stage aims at exploring phenomena relevant to the concept to be taught using collaborative group activities students engage in. The following teaching methods strategies are used:  
- Methods to stimulate thinking.  
- Teaching practice of thinking according to a plan.  
- Self-inquires before, during, and after learning.  
- Teaching practice: considering the expression “I cannot” unacceptable in the classroom. |
| - Principles of Metacognitive Thinking (Jaber, 1999):  
A. The learner should study how to plan, monitor and control, and assess a certain activity he carries out.  
B. The responsibility of learning should gradually move to the learner, and there should be some cooperation and discussion between them. | |
When there is no performance nor a problem faced, students should engage in probing, research, and creative work as soon as possible. The teacher should not present all the information students need at the beginning, so they learn how to get the information independently. | |
- Vygotsky’s theory:
  Knowledge can be built through group discussion and negotiation between the teacher and students as well as among the students in an intellectual and social process that gives meaning and guides students thinking (Abdulkareem, 2000).

- Principles of Metacognitive Thinking:
  Emphasizing the importance of thinking aloud by providing the opportunity to discuss what the learning activities they carry out with other students or with the teacher, which helps give feedback and rethink (Jaber, 1999).

- Teaching Principles of Understanding (Wiggins, & Mctighe, 1998):
  A. Developing students’ independence, which enables them to search for knowledge by themselves; assess themselves accurately; and organize themselves.
  B. Sizar 1984 say: one of the teaching principles of understanding is teaching to achieve understanding basically and essentially means less teaching; it is stimulated rather than being learnt, and it is developed by posing questions to the self more than being asked by others.

- Hypotheses Derived from Piaget’s Theory:
  “Education is effective when its impact spreads out and disseminates throughout the individual's experiences” (Zaitoon, 1982).

- Principles of Metacognitive Thinking:
  A. “Learning should be of value and should help learners be aware of their learning strategies; skills to organize themselves; and the relationship between these strategies, skills, and learning objectives” (Jaber, 1999).
  B. Associating metacognitive thinking with reading comprehension of science in order to achieve understanding (Hussamudeen, 2002).

- Teaching Principles of Understanding (Wiggins and & Mctighe, 1998):
  A. “Teaching for understanding requires us to develop good teaching strategies; to provide opportunities to create meaning; and to assess students’ answers more frequently”.
  B. Learning based on stories and narratives often engages the learner and facilitates his ability to recall compared to learning based on explanations and descriptions provided in textbooks.
  C. The assumptions of Constructivists: application confirms what has been learnt (Zaitoon, 2004).

Stage Three – Concept Introduction:
This stage focuses on collecting and discussing the information and findings each group has arrived at in order to present the basic concept of the lesson.

The teaching methods used at this stage:
- Rephrasing
- Labeling students’ behaviors
- Clarifying and explaining the terms students use in dialogues and discussions

Stage Four – Concept Application:
It means applying what the student has learnt at the previous stages to new situations and activities related to the concept taught, and this can be done in cooperative group activities.

The teaching methods used at this stage are:
- Self-inquiries.
- Intentional conscious selection.
- The strategy: read, role-play, discuss and solve.
- The Assumptions of Constructivism:

Constructivists emphasize that assessment should not be isolated from learning activities; instead it should be a part of their context. They also focus on real introduction through in-depth exploration in order to understand more and draw a profile about the overall development of the learner.

- Principles or Metacognitive thinking:

A. The learner should be trained how to learn knowledge and methods used in the learning process.
B. Emphasizing higher cognitive objectives.
C. Focusing on drawing students attention to thinking in a way that keeps away from thinking about things irrelevant to the lesson. It also focuses on reflecting on all learning activities which they have engaged in(Jaber, 1999).

- Teaching Principles of Understanding:

A. Understanding can be developed and stimulated through the multiple methods of assessment.
B. The methods of assessment include reviews of understanding, which were collected using a variety of formal and informal assessments during the study unit. They are not tests taken at the end of the study, but they are observation, dialogues, quizzes, and self-assessments done by the students and are collected over time(Wiggins & Mctighe, 1998)

Developed Metacognitive Learning Cycle Model: The Empirical Study

This study aimed at investigating the effectiveness of the Developed Metacognitive Learning Cycle Model in developing grade 11 Saudi Female students’ conceptual understanding of physics and their metacognitive thinking skills. To achieve this objective, the researcher used the empirical design known as Pretest-Posttest Non-Equivalent Control Group Design. The research sample included grade 11 female students from the Twentieth High School in Riyadh. The sample was divided into two groups: the experimental group (24 female students) and the control group (24 female students). To measure the prior- and post-performance of the research group, the researcher developed the following tools:

- Conceptual Understanding test, which measures the six aspects of understanding (explanation, interpretation, application, empathy, to have a perspective, to have self-knowledge)
- Self-assessment scale to measure students’ awareness of their ability to use the three metacognitive thinking skills (planning, monitoring and controlling, assessing).
- Note cards to measure how much students practice the three metacognitive thinking skills (planning, monitoring and controlling, assessing) in the practical activity.

The researcher used a number of statistical methods to analyze the data. These methods are: Analysis of Covariance to check the statistical significance of the differences between the students’ average prior and post scores in the conceptual understanding and its six aspects test and the metacognitive thinking scale, the t test to check the statistical significance of the differences between the student’s average post scores in the note cards and ETA-square (η²) to check the effectiveness of the Developed Metacognitive Learning Cycle Model in developing grade 11 female students’ conceptual understanding of physics and their metacognitive thinking skills.

Proceedings of The World Conference on Physics Education 2012
Study Findings:

The study findings have shown the following:

- There is a statistically significant difference (at level ≤ 0.05) between the post average scores of the experimental group students (taught according to the Developed Metacognitive Learning cycle Model) as well as the control group students (taught in the usual way) in the total conceptual understanding test. As for the six aspects, it was in favor of the experimental group. To assess the effectiveness of the Developed Metacognitive Learning Cycle Model in the total conceptual understanding test, the ETA-square ($\eta^2$) was calculated; reaching the value of (86%) in the total test. This percentage is of great influence; indicating the effectiveness of the Developed Metacognitive Learning Cycle Model in developing grade 11 female students’ conceptual understanding, (Figure 2).

![Figure 2. Prior and post Averages for experimental and control groups’ scores in the conceptual understanding test.](image)

- The findings have also shown that “There is a statistically significant difference (at level ≤ 0.05) between the post average scores of the experimental group students (taught according to the Developed Metacognitive Learning Cycle Model) as well as the control group students (taught in the traditional way) in the metacognitive thinking skills (planning – monitoring and controlling – assessing) as measured by the self-assessment scale and the note card measuring how much students practice metacognitive thinking skills in the practical activity”. To measure the effectiveness of the Developed Metacognitive Learning Cycle Model in developing the overall metacognitive thinking skills, the ETA-square ($\eta^2$) was calculated; reaching (98%) in the self-assessment scale and (98%) in the note card; indicating the great influence of the Developed Metacognitive Learning Cycle Model, (Figure 3).
Figure 3. Prior and post Averages for experimental and control groups’ scores for overall metacognitive thinking skills.

- The findings have also shown that there is a positive correlation ($R = 0.982$) between students’ practice of metacognitive thinking skills and their self-assessments in how much the experimental group students use these skills in the practical activity. According to the note cards, their assessment of themselves seems to be consistent with their performance in the metacognitive thinking skills practical activity.

The following is a chart illustrating the Developed Metacognitive Learning Cycle Model:
The Advantages of Using the Developed Metacognitive Learning Cycle Model in Teaching: A Conclusion

There are a number of advantages that can be realized when using the Developed Metacognitive Learning Cycle Model in teaching, and the advantages of the five stages of Metacognitive Learning Cycle are:

1. Bridging the gap between the concepts that has been taught theoretically and what is discovered through experiences and laboratory activities, this is can be achieved by reviewing and directly reflecting on all the activities students carry out and the scientific concepts they acquire.
2. Achieving deep understanding of the learnt materials; consequently, achieving understanding of the acquired concepts in its all aspects, which include the ability to explain and interpret physics concepts presented to the students; the ability to use them in new circumstances and situations (application); having a critical point of view about the scientific content presented; the ability to imagine and empathize (empathy); and being aware of student’s personal habits of learning that form his/her own understanding of concepts or hinder it (self-knowledge).

3. Helping the student acquire a number of skills necessary to carry out learning activities as well as following up his/her learning in a regular and planned way. The metacognitive thinking skills include planning the activity, monitoring and controlling the steps of the activity, and then assessing the plan and the information acquired. In addition, the application of the Developed Metacognitive Learning Cycle develops the student’s manual skills to handle equipment and materials on his own.

4. Stage three – Prior Concept Assessment helps:
   - Bridge the gap between the new knowledge and the knowledge students already have; allowing the learner to control the scientific content and the processes used in learning.
   - Assess and modify misconceptions that students have.

5. Stage five – Post Concept Assessment (after learning) helps judge the extent of achieving all teaching objectives; giving feedback about the effectiveness of the teaching method used; increasing students’ knowledge of themselves; and identifying the strengths and weaknesses in the way they learn.

6. Giving feedback quickly using the informal assessment tools at all the stages of Metacognitive Learning cycle helps control and modify the student’s behaviors according to what the learning event and objectives require.

7. It is well-known that the benefit of the learning cycle can be achieved through good planning of its steps; as provided by metacognitive thinking, which links the learning process to basic functions such concentration, organization, planning, and assessment.

8. This method relies heavily on verbal and written communication at all the stages of Metacognitive Learning Cycle, which helps review understanding and increase conceptual understanding.

9. Developing literacy skills among students using the method of (read, role-play, discuss, and solve). There are a number of measures and standards, to which the teacher should adhere, when using the Developed Metacognitive Learning Cycle in Teaching. These measures are:

1. The teacher should demonstrate the stages of the developed teaching model to the students; specify the objectives and procedures; show them how to fill in the “metacognitive thing skills” card; and interpret some pedagogic terms used in this model such as metacognitive thinking, conceptual understanding, planning, monitoring and controlling, and assessing.

2. He/she should train students how to use the strategy of rephrasing; how to interpret and explain the terms and expression students use; how to thinking out loud; and how to engage in dialogues with the teacher or among themselves.

3. He/she should train the students to take on responsibility of their learning by avoiding to give all the details and instructions related to the activity; instead the teacher should leave plan and draw inferences to them through self-inquiries that they should be trained to use previously.

4. The teacher should set some ground rules in the class before he starts teaching. For example, he should train the students to avoid the phrase “I cannot – I cannot afford...” and start asking question instead in order to achieve the desired goal.

5. He should encourage students to ponder, reconsider, and reflect on all what they think about or do; encourage them to work in groups collaboratively; train them to know and express themselves; and train them to know how they learn by identifying their strengths and weaknesses.
6. He should use encouraging incentives in order to help students effectively participate in the learning process. Such incentives can be competitions, honor, and simple gifts; however, each student should specify the reward he wishes and state the reason for his choice.

7. Understanding should be reviewed at each stage of the developed learning cycle using the formal and informal assessment tools such as exams, interviews, dialogues, inquiries, note cards, etc. in order to ensure that students understand.

8. The teacher should emphasize the importance of learning logs. Each student should keep his work, recordings, and everything he does during the learning process such as assessment sheets before and after learning, activity sheets, achievements, and rewards.

9. The teacher should encourage students practice the six aspects of conceptual understanding, which are explanation, interpretation, application, empathy, to have a perspective, and to have self-knowledge by asking questions that stimulate thinking to help them give deep answers.

Recommendations:

In light of the research findings, the researcher has suggested some recommendations, which are:

1. Using the Developed Metacognitive Learning Cycle Model in teaching the unit “Wave Motion and Sound”, Chapter 5 of Physics taught to 11 graders; as it has a great influence developing the six aspects of conceptual understanding relevant to the scientific content of this unit.

2. Training teachers (before practice) in the faculty of Education how they can use the Developed Metacognitive Learning Cycle Model to teach science.

3. Conducting training sessions for sciences teachers, namely teachers of physics, on how to use the Developed Metacognitive Learning Cycle Model in teaching.

4. The need to use multiple means of assessment before, during, and after learning whilst using the Developed Metacognitive Thinking cycle in teaching. This assessment should include multi-criteria to help students get to know their scientific abilities and review their understanding; in addition, it helps teachers follow up their students' scientific development.

5. The need to provide students with the opportunity to practice the three metacognitive thinking skills (planning – monitoring and controlling – assessing) when carrying out scientific experimental/mental activities.

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Symposium

The Role of Physics Education for Sustainable Development in the Context of Developing Countries: Challenges and Opportunities

A.P. Mazzolini, Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Melbourne, Australia
P. Jolly, Miranda House, University College for Women, University of Delhi, India
M. Sharma, School of Physics, University of Sydney, Australia
A.F. Hasnain, Secretary General, Centre for Physics Education, Karachi, Pakistan

Correspondence should be addressed to: Alex Mazzolini, Swinburne University, FEIS Mail Stop #38, PO Box 218 Hawthorn, Victoria, Australia, 3122 E-mail: amazzolini@swin.edu.au

Abstract

This symposium engaged around 20-30 participants in a focused discussion around two interwoven issues:

(a) exploring new ways to strengthen physics at all levels (from primary to university) by promoting quality physics education, and (b) using physics to help solve sustainable development issues.

A/Prof. Alex Mazzolini, Chair of Asian Physics Education Network (ASPEN), and leader of the Swinburne University Engineering and Science Education Research (ESER) group introduced the theme and spoke of several UNESCO-sponsored physics education support initiatives. He then concluded with a discussion around sustaining physics education innovation through the widespread development of international education research collaboration.

Dr. Manjula Sharma, Director of the Institute for Innovation in Science and Mathematics Education, and Head of the Sydney University Physics Education Research (SUPER) group, spoke about some specific and successful education research collaboration between SUPER and various Thai universities as a way of improving physics education outcomes in both developed and developing countries.

Dr. Pratibha Jolly, ASPEN National Point of Contact for India and Former Chair (2005-2011) of International Commission on Physics Education (ICPE), Commission 14 of International Union of Pure and Applied Physics (IUPAP) spoke about ICPE activities that supported physics education.

Prof. Aziz Fatima Hasnain, Secretary General for the Centre for Physics Education, Karachi, Pakistan, and past ASPEN National Point of Contact for Pakistan, initiated this Symposium theme but unfortunately was unable to attend the WCPE for personal reasons beyond her control.

The aims of the symposium were:

• To review the efficacy of the various activities organized in South Asia to promote physics education, especially the contribution of ASPEN in developing physics education initiatives and research during the last two decades, and their impact on socio-economic development.

• To design strategies for the development of physics education so that physics can have a significant role in solving some of the socio-economic and sustainability problems faced by developing countries.
The Role of Physics Education for Sustainable Development in the Context of Developing Countries: Challenges and Opportunities

A.P. Mazzolini, P. Jolly, M. Sharma and A.F. Hasnain

Introduction

Mr. Ban Ki-moon, the Secretary General of the United Nations, while launching the International Year of Sustainable Energy for All on 12th January 2012, said “We are here to build a new energy future... a future that harnesses the power of technology and innovation in the service of people and the planet.” He further added “It is the golden thread that connects economic growth, increased social equity and preserving the environment.”

This symposium provided a framework for a discussion around the role of physics education in sustainable development as expressed by Ban Ki-moon. This framework included a brief description of the socio-economic situation in South Asia and the issues that block the promotion of physics and its development. The framework also included a discussion around the efforts being undertaken to develop physics in a social context and their impact on the teaching and learning environment, especially as they relate to developing countries.

ASPEN and its activities

The Asian Physics Education Network (ASPEN) was created as a result of the recommendation of the UNESCO Consultative Meeting held in Khon Kaen, Thailand, in November 1981, and for the last three decades ASPEN has been striving to set a tradition of quality physics education in the region. ASPEN has played a role in introducing a significant change in teaching and learning patterns in many developing countries of South Asia. In collaboration with international organizations such as UNESCO, ASPEN has launched physics education projects in the region and has influenced many young physicists who are now pioneering physics education reforms in their own countries. The initiatives include promoting active learning in order to engage students, using hands-on computer- and noncomputer-based physics labs, developing innovative curricula and initiating research in physics education in their respective countries (Alarcon et al., 2005). The ASPEN regional workshops on active learning in physics, which incorporate hands-on, minds-on activity-based learning with low cost experiments, have given a new dimension to the teaching and learning patterns in many developing countries (Cambaliza, Mazzolini and Alarcon, 2004).

The ASPEN Active Learning Workshop (ALW) model was extremely successful, and for many years regional ALWs were very popular. Several UNESCO program managers were themselves ex-ASPEN representatives who were very familiar with, and supportive of, the ASPEN ALW model. Many ALWs were organized in the areas of mechanics, electricity and optics (for example, see Fig.1). Participants’ exit surveys were always very positive, and the ASPEN ALWs were well funded by UNESCO.

Unfortunately, all UNESCO budgets have been severely cut in recent years. In addition UNESCO program managers that have retired have not been replaced or have been replaced by temporary consultants who were unfamiliar with ASPEN, so the voice within UNESCO that champions the deployment of some of its limited budget to ASPEN ALWs is greatly diminished. All this has meant that even the relatively small amount of funding required to coordinate a regional ALW in a developing country is often difficult to find. In addition, many of the ASPEN national points of contact are often very busy and hence do not have sufficient time to seek local and other funding to make up the UNESCO shortfall. These factors have means that the number of ASPEN ALWs has dramatically declined in recent years.

There are however some examples of Asian physics education ALWs that have been supported by other funding agencies or universities themselves. One successful example was a 5-day hands-on Australia-Thailand Southern Teacher Workshop held in September 2010. This initiative was funded by the Australian
Agency for International Development (AusAID) and was jointly coordinated by Swinburne University of Technology (in Australia) and Chulalongkorn University (in Thailand). The workshop helped train 22 physics, mathematics, chemistry, biology and geology academics from the Faculty of Science, Chulalongkorn University in various teaching techniques that could be used to engage students, in particular an “Active Learning” methodology designed for lectures, laboratory sessions, project-based activities and tutorials (see Fig. 2). The training workshop was then adapted and used to train high school teachers from the underprivileged Southern Border Provinces of Thailand in order to improve the level of science education in their region.

A second example is an Asian ALW that was primarily funded by a Swinburne University Education Innovation grant and a small additional UNESCO travel grant. This 3-day ALW, which covered the topics of mechanics, heat, optics and electricity, was held at Swinburne’s Kuching campus in Sarawak in 2008. There were 24 participants at this workshop with half of these from Swinburne’s Kuching Campus and the other half from various universities throughout the region (Brunei, Cambodia, Timore Leste, Indonesia, Malaysia, Nepal, and Thailand). The facilitators came from Australia, USA and The Philippines. Again the exit survey from this ALW was extremely positive.

These two successful examples were feasible because of collaboration and networking between ASPEN representatives, but the skills and experience needed to successfully seek sufficient funding from several sources for such workshops can be a significant impediment. Hence it is hoped that in the future UNESCO will again be able to offer its earlier level of support for ASPEN ALWs.

**UNESCO ALOP Program**

The highly-successful UNESCO Active Learning in Optics and Photonics (ALOP) workshop program has been introduced to many developing countries, and teachers in these countries have been trained in order to (a) improve their understanding of optics and photonics; (b) develop their ability to actively engage their students; and (c) develop their ability to use local, low-cost resources to complement their classroom teaching. The ALOP workshops, which are aimed at the introductory university and upper high school level, have changed the perception that teaching a wide range of optics concepts (from ray tracing, to interference to optical communications) requires high cost equipment (Alarcon et al., 2010). The ALOP program was first proposed by UNESCO in 2003 and the first ALOP workshop was held in 2004. Under this program, ALOP has developed a comprehensive set of activities using an active learning (AL) structure. This AL structure is based on a ‘Predict, Observe, Discuss, Synthesise (PODS) learning cycle, and including a detailed ALOP manual describing the learning activities and a teacher’s guide. ALOP is a 5-day hands-on, minds-on workshop designed to engage teachers in the active learning philosophy applied to the teaching of optics and photonics. ALOP also introduces the concept of action research and the quantitative evaluation of the improvement in students’ conceptual understanding of optics, so that teachers have a tool to measure the effectiveness of their teaching innovations in optics.
To date there have been 18 official UNESCO ALOP workshops in many developing countries of Africa, South and Central America, Asia and Eastern Europe, and physics educators from approximately 50 different countries have been trained. The ALOP program has also been further disseminated via many additional locally-coordinated and locally-facilitated workshops. These additional workshops (mainly in North Africa, South America and Asia) have been organized by physics educators who have previously participated in official ALOP workshops. The ALOP program development team was awarded the SPIE (International Society for Optics and Photonics) Educator Award in 2011.

**The Sydney – Thailand partnership: A model for localised development of expertise**

Over eight years, an in-depth partnership has developed between The University of Sydney and various universities in Thailand, for example Mahidol University and Chiang Mai University. The partnership has seen physics education students undertaking part of their PhD research project work with the Sydney University Physics Education Research (SUPER) group. The students have gained expertise in teaching development initiatives ranging from misconceptions research, active learning to learning in the laboratories. Over the last two years, the partnership has been strengthened by Dr. Pornrat Wattanakasirich, an Endeavour Research Fellow working on Interactive Lecture Demonstrations in the area of thermal physics. The Thai scholars, upon return to their country are contributing to teacher education, teacher professional development and gaining prominence for physics education within their universities – building capacity within their local regions.

**ICPE and its Activities**

The International Commission on Physics Education (ICPE), commission 14 of the International Union for Pure and Applied Physics (IUPAP) was established in 1960. It was born out of the realization that unlike research speciality areas, physics education lacks spontaneous international linkages even though teaching of physics and education of physicists is of concern to all. Indeed, there is a great deal of commonality in the problems faced by various countries despite the diversity in their social and cultural fabric. The primary mandate of the Commission is to promote the exchange of information and views among the members of the international community of physicists in the general field of Physics Education including:

- collection, evaluation, co-ordination and distribution of information concerning education in the physical sciences at all levels;
- information relative to the assessment of standards of physics teaching and learning;

suggesting ways in which the facilities for the study of physics at all levels might be improved, stimulating experiments at all levels, and giving help to physics teachers in all countries in incorporating current knowledge of physics, physics pedagogy, and the results of research in physics education into their courses and curricula.
The charted path of ICPE has impacted physics education globally in many significant ways. Inasmuch as promotion and support of international conferences is one of the main ways in which the commission seeks to achieve its aims, the list of ICPE supported conferences is long. Over the years, there has been a distinct shift in the profile of the participants and the foundations on which the conference themes rest. One of the flagship programmes of ICPE is the Physware Series of Workshops. This aims to create and strengthen the regional and international networks of physics educators who can impact the quality of physics education at the tertiary level, especially in the developing countries. Physware emanates from shared concerns on the lack of high-quality education in physics with detrimental consequences on scientific research and socio-economic progress. This concern was voiced through a resolution on Importance of Active Learning and Hands-on Physics Education adopted by the International Union for Pure and Applied Physics (IUPAP) at its 26th General Assembly held at Tsukuba, Japan, in October 2008. It led to a Memorandum of Understanding between IUPAP and ICTP in October 2009, affirming cooperation for organizing a series of Educate the Educator Workshops for five years. IUPAP works on this through its International Commission on Physics Education (ICPE.) The pilot 2-week long workshop was held at Trieste in February 2009. The next will be held in Delhi in November 2012, and then it will alternate each year in venue between Trieste and a developing country. The presentation will elaborate on the salient features of Physware workshops.

**UNESCO Initiatives on Education for Sustainable Development**

UNESCO is currently finalizing the development of a 10-week, on-line, short course on sustainable development in science, which is called ‘Sustainability Science’ (see UNESCO & CONNECT-Asia, 2012). This course has been designed to be taken by students at Asian universities during the final year of their undergraduate studies in science or engineering. The course aims to give these students an understanding and appreciation of sustainability issues facing developing (and developed) countries, and how science and engineering innovation may alleviate some of these issues. It is hoped that such an understanding will help inform graduates as they enter the workforce, so that they can contribute to positive change in science and engineering sustainability practices in industry.

Each of the 8 modules was developed by experts from universities in the extended Asian region. This online course will give engineering and science students the skills and knowledge they need to understand how their discipline can assist in solving the problems of sustainable development. The Sustainability Science course is part of UNESCO’s COMPETENCE (Comprehensive Programme to Enhance Technology, Engineering and Science Education in Asia) project. The course is coordinated by UNESCO Jakarta together with the Center for Sustainability Science (CENSUS), Hokkaido University, Japan.

The Sustainability Science course provides a model for sustainability education among higher educational and governmental institutions in the Asian region. The course develops a comprehensive framework of sustainability ideas that are well matched to any undergraduate science or engineering program. The course covers the following themes:

- Introductory overview to sustainable development.
- The results of human activity (including climate change, and loss of biodiversity & ecosystem services).
- What humans consume (including water resource management & water issues, natural resource management, and energy issues).
- What humans will need in the future (including health & human well, and food security).
- Conclusion (including the synthesis of ideas – connecting previous topics to the “big picture”).
- Professional Practice: Sustainable development project design (industry- or community-based).
Role of Education Research in Sustaining Physics Education Development

Finally, there is the issue of sustaining physics education in developing countries so that it can support the development of physics, which in turn can support sustainable development. It is the authors’ belief that sound education research should underpin physics education initiatives. The Sydney University Physics Education Research (SUPER) group and the Engineering and Science Education Research (ESER) group at Swinburne University have both independently started to collaborate with academics from several developing countries in the Asian region in order to foster physics education research (see for example Kaewkhong et al., 2010). The eventual hope is that these collaborations will lead to a critical mass of education research expertise in the extended Asian region that will drive informed physics education reform.

The authors believe that in the past, developing countries have spent a considerable amount of their resources in having their best students trained in discipline-based physics research at international research centres. When these students return to their homeland they do not have access to the expensive equipment infrastructure needed to develop their physics research locally. Perhaps it is time for developing countries to consider encouraging some of their best students to undertake physics education research (PER) rather than just physics discipline research. PER is easily transferable to developing countries as it often does not require expensive infrastructure. Locally-based PER groups are relatively easy to develop, and the results of PER can be easily implemented to improve learning and teaching outcomes in developing countries.

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Exploring the Rolling Shutter Effect Using a Computer Scanner

Bor Gregorcic and Gorazd Planinsic, Faculty for Mathematics and Physics, University of Ljubljana, Slovenia

Abstract

The inclusion of high-tech and low-priced gadgets in a physics curriculum can have a great effect on students’ attitude towards science and their motivation for learning, especially if a hands-on activity is used, which also takes into account other factors that enhance classroom interest. The fact that nowadays almost everyone owns a mobile phone with a camera makes the content of the presented activity very appealing to students. Using the scanner, they can gain, through their active engagement, an understanding of the rolling shutter operation in mobile phone cameras. The phone camera can then be used to examine fast rotating objects, such as fans or propellers and to make estimates about their spinning rates. This puts the mobile phone camera in the role of a measuring device, which can be used by students in different situations in their life, not only in the classroom.

Introduction

To educators, finding student activities that are interesting to the students, of appropriate difficulty and helpful in developing their knowledge and skills is of great importance. If the activity is relatively cheap to perform and relates to students’ everyday lives, this is a great advantage as well. The presented activity aims to develop better understanding of spatial relations and relative motion. It employs a simple experiment, that can be used in a hands-on activity or a classroom demonstration. The motivation for the activity are photographs of spinning airplane propellers, taken by phone cameras, or, if sports are of greater interest to the students, photo finish images of cycling races. These two contexts are connected to students’ everyday lives and present a good starting point for the activity. The fact, that almost everyone has a mobile phone of their own, makes the topic even more interesting. The availability of the equipment used in the activity, encourages students to make experimentation a part of their everyday life.

Rolling shutter effect

Photographing fast moving objects has always been a challenge. Mainly because cameras do not collect an image in an instant, but take some time to do so. There are different mechanisms of capturing an image on a film or an electronic sensor, but none of them are instantaneous. A fine example of a rapid motion is a spinning propeller of an airplane. When photographed by a phone camera, the resulting images are not what most of us would expect (figure 1).

This effect is a result of the fast motion of the propeller and the way in which the phone camera captures images. A similar effect was first observed by late 19th century photographers, who started using the focal plane shutter, also often called the rolling shutter, to take photographs of fast moving objects. A thin slit would be moved across the surface of the photographic plate or film from one to the other side of the frame. Light would hit the film during the passing of the slit. This means that one side of the frame would be exposed to the light a fraction of a second before the other. This delay would be negligible in most everyday situations, but not when taking pictures of fast moving objects, like spokes of a spinning wheel or a propeller of an airplane.
The way in which most phone cameras capture images is similar to the way the mechanical rolling shutters work. But instead of a mechanical shutter, the phone camera electronically determines which part of the CMOS light sensor is collecting light and for how long it does so. This is usually done row by row. The START signal sweeps the sensor from top to bottom (or from left to right) and is followed shortly after by the STOP signal, which sweeps the sensor with the same speed in the same direction but with some delay, so that effectively only a narrow strip of the sensor is collecting light at the same time. The delay depends on the lightning conditions. More light means shorter delay between the START and STOP signals. To simplify, in good lightning conditions, the phone camera is recording the image row by row from one to the other side of the sensor with a finite speed (“Shutter operations,” 2011). This is very similar to the mechanical rolling shutter. One can think of the phone camera as a desktop scanner. Moving the paper while the scanning is in progress will result in some usually unwanted effects.

As the rolling slit (“the scanning line”) advances through the frame of the camera, the propeller blades rotate. For a very vivid and clear demonstration of the effect this has on the final photograph, watching the video listed in the references (Chupron, 2012) is strongly advised, as it explains this effect very clearly in a matter of seconds.

Photographs of spinning propellers with rolling shutter effect exhibit a similar asymmetric pattern. A “fork” of blades can be seen pointing to one side. This is the side where the propeller blades travel in the opposite direction of the “rolling shutter”. As intersections between the rolling slit and the blades are more frequent and take less time, this results in more blade images that are quite sharp. On the other side of the propeller, the blades travel in the same direction as the rolling slit, which results in blurry images of blades, which may not even be connected to the central axis and are seemingly floating in midair on the side of the motor.

The directions of rotation and scanning therefore determine the orientation of the “fork”. By knowing two of these three directions (scanning direction, spinning direction and orientation of the “fork”), one can determine the third. For example, by knowing which way the propeller rotates, one can determine the direction in which the rolling shutter scans the sensor by looking at the image produced.

The rolling shutter effect was not the first case where these kind of patterns were observed and studied. Peter Mark Roget described in 1824 a curious illusion that occurs when wheels of a moving train are observed from a distance through a palisade with narrow vertical slits (Minnaert, 1954). To observe and manipulate this phenomenon, visit the link provided in the references (Bach, 2007). The java applet on the site lets you manipulate the angular velocity of the wheel and the translational velocity of the palisade. The Roget’s palisade illusion is basically the same phenomenon as the rolling shutter effect. Although in this case, there is more than one slit moving past the spinning wheel. Persistence of vision is what makes it look like a somewhat static image moving with the wheel.

**Figure 1.** Phone camera snapshot of a spinning propeller

The blades seem bent, stretched and bent. Some even appear to be suspended in midair, not being connected to the axis of rotation.
Another example of the rolling shutter effect can be seen in photo finish photographs of cycling races. As we have pointed out earlier in this article, we can determine the direction of the scan, since we know both the direction of the spinning wheel and the orientation of the “forks”, which can be clearly seen pointing upwards in Figure 2. One may also notice that the background is uniform in the horizontal direction. The reason for this uniformity is the special way in which these finish photographs are taken. The frame of the camera taking this photographs is actually just a few pixels wide and carefully centered on the finish line, while the camera is taking a few thousand frames (lines) per second. These pixel-wide photographs are then added together side by side to form a photograph in which every vertical column is a pixel wide image of the finish line at a different time.

The wheel’s translational velocity is what determines the scanning velocity in this case. The wheel is rolling on the ground. This means that \( v = \omega R \), where \( v \) is the translational velocity of the wheel, \( \omega \) the angular velocity of the wheel and \( R \) the radius of the wheel. The translational velocity determines the time it will take for each slit to pass the wheel by, therefore it is equal in size to the scanning velocity. This last example of photo finish image brings together the rolling shutter effect and the Roget’s palisade illusion. The rolling shutter effect can be clearly seen, but differs from the propeller effect in a sense that the scanning and rotational velocities are not two independent parameters.

Understanding of spatial relations is of great importance for making sense of this phenomena. This can be made much easier for the students, if an equivalent situation is first dealt with in a simple experiment. The computer scanner is introduced for this purpose.

A simple experiment using a computer scanner

The sequence in which the scanner captures the image is basically the same as in the phone camera. The main difference is that the light sensor travels along the frame together with the light that illuminates the document, photograph, or any other scanned object from below. However, each line is, like in the case of the phone camera, captured at a different time and later combined line by line to form a final image. This is appropriate for scanning objects, such as documents, that are placed on the glass plate.

We introduce a wheel, that spins just above the scanning surface, as the scanner progresses. The size and pace at which the process goes on is perceivable to our eyes, in contrast with the tiny sensor in a phone camera with no moving parts. This is a great opportunity for developing a better sense of the spatial relations that govern the image formation. Attention is devoted to analysis of relative motion of the scanner head and points on the rotating wheel. Using this experiment, we simulate what happens in the phone camera, but at a much slower pace.

The “wheel” for this experiment was made from a CD, on which a circle of paper with 16 radial lines drawn on it was attached. The CD was fixed to an electric screwdriver, powered by a variable voltage source. The scanning rate can also be changed by adjusting the resolution of the scanned image prior to scanning. Lower resolution means that the scanning will be faster, as there is less data to process.
Quantitative analysis

The image characteristics depend on the ratio of the scanning velocity and the tangential velocity of the outermost part of the CD. The most simple analysis can be done by observing the spacing between two consecutive curves, as they appear in the image. In order to make the analysis simple, we will focus only on distances between the curves on the rim of the disk.

Let $a$ be the distance between two consecutive curves on the disc, as can be seen in figure 3. In order to simplify the calculation, let us assume that $a$ is so short, that it can be considered a straight line, although it is in fact a part of the circumference of the wheel.

Let $b$ be the distance between two consecutive curves on the opposite side of the disc, the side where the “fork” is formed. Let the scanning velocity be $v_s$ and the tangential velocity of the wheel on its outermost radius be $v$.

![Figure 3. Scanned rotating CD image with marked distances a and b](image)

An example of a scanned rotating CD image with marked distances $a$ and $b$ and velocities $v$ and $v_s$. $v_a$ and $v_b$ are the velocities of the rim of the disk at the far left and far right side. They are both of the same size and of opposite direction.

The actual distance between two consecutive lines on the disk

$$d = \frac{2\pi R}{N}$$

where $N$ is the total number of lines and $R$ is the radius of the disk.

The time it takes for two consecutive drawn lines to cross the line on the left side

$$t_a = \frac{d}{v_s - v_a} = \frac{d}{v_s - v}$$

The time it takes for two consecutive drawn lines to cross the line on the right side

$$t_b = \frac{d}{v_s - v_b} = \frac{d}{v_s + v}$$

The absolute value of $t_b$ is always less than that of $t_a$. This means that the frequency of the passing of the spokes over the scanning line is higher at $b$.

Because the scanning velocity is constant, distances $a$ and $b$ are proportional to $t_a$ and $t_b$.

$$a = t_a v_s \quad b = t_b v_s$$

WCPE 2012, Istanbul, Turkey
The ratio of the apparent distances between spokes on the left and the right side of the image \( \eta = \frac{a}{b} \) can be expressed in terms of the ratio of \( v \) and \( v_s \):

\[
\eta = \frac{1 + \frac{v}{v_s}}{1 - \frac{v}{v_s}}
\]

The equation can be rearranged to express the ratio of velocities \( \frac{v}{v_s} \).

\[
\frac{v}{v_s} = \frac{\eta - 1}{\eta + 1}
\]

Let us verify the equation (6) for some limiting cases. For \( v = 0 \) (disk is not spinning) we get \( \eta = 1 \). As expected this means that distances on both sides are equal. For \( v \) approaching \( v_s \), the ratio \( \eta = \frac{a}{b} \) becomes infinite. We will soon be able to interpret this result.

If the scanning speed \( v_s \) is smaller in magnitude than the tangential speed \( v \), we notice that \( \eta \) is negative. The expression (4) gives us a negative distance \( a \), for \( v > v_s \). How can we interpret this? Look at the figure 4. Image on the left shows a scan of the stationary disk and image on the right shows a scan of a rotating disk. As we can see, the arrows on the left side in the latter image are pointing upwards.

![Figure 4. Scan of stationary disk (left) and the same disk rotating with \( v > v_s \) (right)](image)

Note that the arrows on the left side of the right image point in the opposite direction than in the case when disk is stationary.

This is because these arrows are moving faster than the scanning line. As they cross the scanning line from behind, their tips get scanned first and their tails last. Thus they appear upside down compared to the orientation of original arrows. This can only happen if \( v \) is larger than \( v_s \) and only on the side where both velocities point in the same direction. The negative sign of \( a \) when calculated from equation (4) can be interpreted as mirroring of the scanned object. Therefore, when we insert the value of \( \eta \), obtained from an image as the ratio \( \frac{a}{b} \), into equation (7), we must put in a negative value, if \( v \) is larger than \( v_s \).

We recognize the cases where \( v > v_s \) by the “detached” lines – lines that do not connect to the center of rotation in the image. To get a better idea of how to recognize such a case, see the next chapter’s table of figures 5 to 9. Figures 8 and 9 are both examples of \( v > v_s \).

If the disk and the scanning line travel at the same velocity and in the same direction, no crossings will take place. At least until the drawn lines, due to their rotary motion, start to change their tangential velocity direction from vertical towards horizontal, thus allowing the scanning line to catch them and cross them eventually. This is the reason why the spacing between curves at the left side of the image increases as the ratio \( \frac{v}{v_s} \) is approaching 1.
Roget’s palisade illusion and the photo finish photographs are both cases of $v/v_s$ ratio being 1. In both cases, wheels are rolling on the ground and the slits are standing still.

**Student project activity**

Analysis of the scanned images of rotating disk can also be used as an exciting student project. A typical student task would include study of the simple theory, design of the spinning disk, measurements and comparison of calculated and measured results. On a more advanced level, an open ended task can be given to students, which requires of them to explain the weird patterns in the images.

Results of typical measurements and calculated values are summarized in figures 5 to 9. The ratio of distances between consecutive spokes on either side of images were determined for several spinning velocities. The velocities were measured using a stopwatch and a measuring tape. The frequency of rotation was determined by counting laps, while measuring time, from which the tangential velocities were calculated using the following expression

$$v = \frac{2\pi R}{\tau_o} \quad (8)$$

where $R=12$ cm, the radius of a normal CD.

![Figure 5. Scanned stationary disk](image)

- Scanning velocity $v_s=4.6$ cm/s
- Tangential velocity $v=0$
- $\eta_{calc}=1.0$
- $\eta_{meas}=1$

![Figure 6. Scanned rotating disk](image)

- Scanning velocity $v_s=4.6$ cm/s
- Tangential velocity $v=3.5$ cm/s
- $\eta_{calc}=3.0$
- $\eta_{meas}=3$
The scanner - a powerful didactical tool

The computer scanner was first used by us in spring 2011 in a relative motion based activity with 66 first year physics students. Students were asked to describe the motion of an object moving across the scanner window during the scan by looking at images produced by the scanner. A survey showed that most of the students found the activity interesting and about half of them expressed interest in performing similar experiments at home. This is in agreement with Bergin (Bergin, 1999) who linked classroom interest to different individual and situational factors. Novelty of the activity and relevant content are two factors that can be argued to have made scanner activities interesting for the students. Positive attitudes towards activities with the scanner encouraged us to design more activities with it, incorporating hands-on approach as another important factor for increasing interest and student engagement.

The activity described in this article was used in laboratory work for the third year physics students at the Faculty of mathematics and physics, University of Ljubljana in a one semester course of Didactics of physics. One group was given a task to explore the patterns in the scanned images of a rotating CD attached to an electrical screwdriver, as described above. The other group was given an electrical motor

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**Figure 7.** Scanned rotating disk
Scanning velocity \( v_s = 4.6 \) cm/s
Tangential velocity \( v = 4.8 \) cm/s
\(|\eta_{\text{calc}}| \approx 50\)

\( a/b \) in the picture is too large to be valid for our approximation of short distances. \( \eta_{\text{meas}} \) is in this case considered to be infinite.

**Figure 8.** Scanned rotating disk
Scanning velocity \( v_s = 4.6 \) cm/s
Tangential velocity \( v = 8.8 \) cm/s
\(|\eta_{\text{calc}}| = 3.2\)
\( \eta_{\text{meas}} \approx 3\)

Notice the “detached” lines, that are not connected to the axis of rotation.

**Figure 9.** Scanned rotating disk
Scanning velocity \( v_s = 4.6 \) cm/s
Tangential vel. \( v = 18.8 \) cm/s
\(|\eta_{\text{calc}}| = 1.6\)
\( \eta_{\text{meas}} \approx 1.5\)
with an identical CD attached to it, but spinning at a much higher rate, which was also adjustable. This group had the same task, but they had to use their mobile phone cameras instead of the scanner.

The group who used the scanner produced very accurate qualitative description and explanation of the patterns formed and their evolution with the increasing of the spinning rate of the CD. When they were shown the images that the other group had produced with their phone cameras, they were able to recognize and explain to the phone camera group the mechanism of capturing of a photograph in a mobile phone camera.

The advantage of the scanner is in its slow operation and observability of the scanning process. The activity enables direct manipulation of the involved parameters and allows students to observe the process of capturing in real time. This allows students to gain understanding through experiment, rather than through explanation. The hands-on approach and the novelty of the subject turned out to be a great motivation for exploration by the students.

A similar activity was performed by post graduate students of educational physics on the same faculty. Here, the aim of the activity was to capture images of the rotating CD with the scanner and compare the a/b ratios measured on the images to the ratio $\eta_{calc}$. The ratio $\eta_{calc}$ was calculated from $v$ and $v_s$, using equation (6). The students produced written reports of the laboratory activity.

A workshop aimed at gaining understanding of the rolling shutter effect in mobile phone cameras was conducted at the Heureka Project annual conference in Nachod, Czech Republic, in October 2012. The scanner was once again used to simulate the capturing mechanism inside a mobile phone camera. The teachers that participated in the workshop reported that it helped them to reason and predict the rolling shutter effects. They were able to transfer their knowledge about the patterns and their formation to situations, where a mobile phone camera was used instead of the scanner, to capture fast moving objects, such as oscillating strings. The possibility of using the mobile phone camera to measure propeller spinning rates or frequencies of string oscillation was highly appreciated among teachers. Other possibilities of using the mobile phone camera as a measuring device are still to be explored. We hope for and encourage educators to develop new ideas of using the highly accessible mobile phone camera for educational purposes.

Conclusion

In each of the activities mentioned above, the scanner played a crucial role. Its advantages, slow operation, size and availability make it a valuable didactic tool. The accessibility of the equipment (scanners and mobile phone cameras) makes this activity relatively cheap, simple to do and relevant to students’ everyday life. Besides that, the very accessibility of the equipment turned out to be a great motivational factor for the participants.

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Students’ Knowledge about the Gravitational Assist

Tomáš Franc, Astronomical Institute of Charles University, Faculty of Mathematics and Physics, Charles University in Prague.

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E-mail: Tomas.Franc@mff.cuni.cz

Abstract

A probe flying around a planet or a satellite changes its direction and speed because of the gravitational attraction of a much more massive body. NASA maintains a powerful web interface (called HORIZONS) where we can obtain data of many missions which used the technique of the gravitational assist. With these data we created our original animations of space flights to other planets (or asteroids or comets) and several diagrams like velocity-time diagram – all for better understanding of the gravitational assist. A lecture about the gravitational assist was prepared by two reasons: 1) as an informative lesson about this technique (which could attract students to physics or astronomy) and 2) as an explanatory lesson (how this technique works, why it is used). Two questionnaires were prepared for the lecture, one was given to students before the lesson and the other one after the lesson. We asked students whether they had ever heard about the gravitational assist, how this technique works, which advantages it could have etc. In this paper we present some parts of the lecture about the gravitational assist and findings from the two questionnaires.

Keywords: gravitational assist, animation, trajectory, velocity-time diagram

Introduction

Astronomy or cosmonautics are in general very interesting parts of physics for students (that was proved in many researches like in the study by Kekule & Žák (2009)) but these parts are not included in obligatory curriculum in the Czech Republic. High school students learn about them only in elective physics courses and very often they hear only about standard topics like Kepler’s laws, star evolution, etc. and very little about cosmonautics. We consider it as a loss because there are many topics in astronomy that can be included into regular lessons. In this paper we would like to present one of these topics – the gravitational assist. During its explanation students could learn how to use the law of energy conservation and linear momentum, they could work with different frames of reference, etc. and everything on the background of gravity.

For this aim we prepared original materials and a lesson (presentation) for learning about the gravitational assist.

Creating Diagrams and Animations

Franc (2011) presented creating diagrams that we use, so we present only a very short instruction here. On the HORIZONS Web-Interface (Jet Propulsion Laboratory, 2012) we can download data sets of coordinates for many missions which used the technique of the gravitational assist (ordered according to their launch date): Pioneer 10 & 11, Voyager I & II, Galileo, Ulysses, NEAR Shoemaker, Cassini, Stardust-NExT, Rosetta, Messenger, Deep Impact – EPoxy, New Horizons, Dawn, Juno. We obtained text files, imported data into Wolfram Mathematica (Wolfram Research, 2012) and with the use of usual commands (e.g. Plot, ListPlot, Show, Graphics, Line) we created many plots, diagrams and animations – especially velocity-time graphs, pictures and animations of trajectories in 2D and 3D. For animations we used the command Manipulate. All materials – especially animations – are available at Tomas Franc homepage (Franc, 2012), for viewing it is not necessary to have Wolfram Mathematica, the Wolfram CDF Player (Wolfram Research, 2012) has the full functionality for controlling animations and viewing diagrams (including rotating and zooming 3D graphics) and it is for free. See the example of Cassini spaceflight 2D animation in Figure 1.
Our Lesson about the Gravitational Assist

We can divide the lesson into these parts: (1) a discussion when the gravitational assist is used and why it is important; (2) an explanation how this technique works; (3) interesting information about selected missions, animations and images obtained by these probes. Let us give three examples of that presentation.

How Spacecrafts Travel in the Solar System

During the first lesson we found out that students had no idea about spaceflights, for example how the typical trajectory of a spacecraft can look like. So for the next presentation we added the Figure 2. After a short discussion students found out which trajectory was the right one and that it was evident – because the same laws are valid as for spacecrafts as for planets – Kepler’s laws – so the spacecrafts’ trajectories are ellipses or their parts (when the spacecraft is escaping from our Solar system, its trajectory is a part of hyperbola).

Going Closer to the Sun – the Spacecraft Must Break Down

One fact was very surprising for our students: when we want to reach Mercury or the Sun, the spacecraft has to slow down and we explain it as follows. We use the second Kepler’s law and the equation

\[ \frac{v_p}{v_a} = \frac{r_a}{r_p} = \frac{1 + e}{1 - e} \]

where \( v_p \) (\( v_a \)) is the velocity of a planet in the perihelion (aphelion), \( r_a \) (\( r_p \)) is the distance of the planet from the Sun in the perihelion (aphelion), \( e \) is the eccentricity \((0 < e < 2)\) of planet’s orbit. So a planet is faster in the perihelion than in the aphelion. For instantaneous speed of a planet at any point in its orbit we can derive the equation (\textit{vis-viva equation})

\[ v = \sqrt{\frac{1}{a} - \frac{1}{r}} \]

where \( a \) is the semi-major axis, \( r \) is the actual distance of a planet from the Sun, \( G \) the gravitational constant and \( M_\odot \) the mass of the Sun. From these two equations we get the result showed in the Figure 3. And again, the same equations (1) and (2) are valid also for spacecrafts. When we want to change our orbit from the blue one to the red one in Figure 3, we have to slow down. Let’s have the semi-major axis \( a_1 \) for the original (blue) orbit, for the new (red) trajectory let’s have the semi-major axis \( a_2 \) and because this new trajectory gets us closer to the Sun: \( a_1 > a_2 \). In the aphelion A (which is the common point for both orbits, so the distance \( r \) from the Sun is the same for both orbits) we have (see Figure 3 for notation)

\[ v_1 > v_3 \]

and because \( a_1 > a_2 \) we see that \( v_1 \> v_3 \), which means slowing down. But in the new perihelion \( P_2 \) the spacecraft will be faster than in the original perihelion \( P_1 \).

Velocity-time Diagrams

From the HORIZONS Web-Interface (Jet Propulsion Laboratory, 2012) we can get (except for coordinates) velocities related to the Sun and to the chosen Observer Location. We chose one mission which used the gravitational assist for accelerating (related to the Sun) – Galileo mission and one mission which used the gravitational assist for decelerating (related to the Sun) – Messenger mission. We created for both missions two diagrams, one for speed related to the Earth and one for speed related to the Sun (we intentionally chose missions that used the gravitational assist with the same planet – the Earth). \textit{Wolfram Mathematica} command: ListPlot. See Figures 4, 5, 6 and 7. After seeing the graph in the Figure 5 for accelerating related to the Sun, students can estimate the shape of the graph in the Figure
7 for decelerating related to the Sun. But after seeing the graph in the Figure 4 for speed related to the Earth (and accelerating relative to the Sun), students are not able to estimate the shape of the graph in the Figure 6 for the speed related to the Earth (and decelerating relative to the Sun) – students expect that the spacecraft decelerates when approaching the planet and accelerates when departing from the planet. They are surprised when they see the correct solution, but they admit that this shape is the right one when they realize that the gravitational force from the planet rises when the spacecraft approaches the planet (the fact that the spacecraft accelerates or decelerates related to the Sun is not important here) and that means that the spacecraft accelerates and vice versa for departing from the planet. Students are also very surprised that the diagrams in Figures 4 and 6 are “too perfectly” symmetrical, so we have to explain that the data are real and obtained from HORIZONS Web-Interface (Jet Propulsion Laboratory, 2012). In these two diagrams, we chose the closest approach to the planet as the time = 0 and we chose the same time interval both for approaching and departing.

The Questionnaires

Until now we have given this lesson three times (for different students). We gave students questionnaires before and after the lesson to find out whether students know anything about the technique of the gravitational assist and whether they consider this topic interesting. We have responses from 37 high school students (and from 5 high school teachers but the latter sample is too small so we will not include teachers’ results here). The results will be used for the main future research of students’ knowledge about selected gravitational phenomena.

The Questionnaire before the Lesson about the Gravitational Assist

Because we expected that students would not know anything about the gravitational assist, we gave them following short information about this technique:

The gravitational assist is a name for the technique used by flights of spacecrafts when a spacecraft is guided to fly around a planet and the planet accelerates or decelerates the probe and changes the probe’s flight direction.

After this information, several questions followed:

Q1) Have you ever heard about this technique?

Q2) What other advantages can the gravitational assist have (except for the above mentioned speed and flight direction changes)?

Q3) What physical law is this technique based on?

Q4) In which situation can it be useful to slow down the probe?

Q5) Are you interested in astronomy (cosmonautics)?

Here we will present our findings.

Q1: 12 students have already heard about the gravitational assist (but very often only “by the way” as a short remark that such technique exists). So 66 % students have NOT ever heard about the gravitational assist.

Q2: 17 students (46 %) did not answer this question or they did not know the answer. At one hand it corresponds with our findings from Q1 (students did not know this technique), but on the other hand they could figure some answer out, especially the following most common right answer. 10 students (27 %) wrote that when this technique is used, energy or fuel is saved. But this technique has more advantages (see below). Other answers were not very frequent: two students think that this technique has no advantages, 2 students wrote that the lifetime of the spacecraft is longer thanks to it. But we also got one very important answer – one student knew that thanks to this technique the crew of Apollo 13 had been saved.

Q3: 17 students (46 %) did not answer this question or they did not know the answer. 12 students (32
5% wrote “gravity” or “the gravitational law”. 5 students (14 %) think that this technique is based on the centrifugal force (so they consider FORCE as LAW, but maybe it is connected with the result of Q1 – students do not know this technique and perhaps they were nervous). Other answers were not frequent. Two students mentioned Newton’s laws of motion, three students Kepler’s laws. Only ONE student answered that the technique of the gravitational assist works thanks to the law of energy conservation.

Q4: 5 students (14 %) did not answer this question or they did not know the answer. 6 students (16 %) answered that the spacecraft is sometimes too fast (but they did not give any explanation what they meant with this statement), so we have to slow it down. The most frequent answer: 13 students (35 %) consider it is useful to take detailed images when the probe gets closer to the planet – they did not realize that the spacecraft accelerates when it approaches the planet, see discussion above and Figures 4 and 6. Four students wrote that we have to slow down the spacecraft when we want to avoid the crash (with the planet or another spacecraft). And 13 students gave different answers (for example preventing the probe from escaping the Solar System, when we want the spacecraft to get back to the Earth or when the probe lands).

Q5: 14 students (38 %) are not interested in astronomy or cosmonautics. 17 students (46 %) have little interest (they sometimes read articles on the internet). And 6 students (16 %) are interested very much (they like searching for new information on astronomical websites).

The Questionnaire after the Lesson about the Gravitational Assist

After the lesson we gave students another questionnaire, some questions were the same as in the previous one.

Q6) What other advantages can the gravitational assist have (except for previously mentioned speed and flight direction changes)?

Q7) What physical law is this technique based on?

Q8) If the spacecraft is accelerated during the flight around the planet, will anything happen to the planet?

Q9) In which situation can it be useful to slow down the probe?

Q10) Is this topic interesting enough for you to search for more information?

Students’ answers:

Q6: Only 2 students did not answer this question. For 23 students (62 %) the main advantage is saving energy or fuel. 12 students (32 %) remembered from the presentation that another advantage is the possibility to shorten travel time (or simply to save time). 15 students (41 %) mentioned escaping from the Solar system, 9 students (24 %) wrote about reaching Mercury or the Sun. Four students pointed out that this technique allows sending spacecrafts with lower masses. Some students wrote more than just one advantage. All answers taken together contain all advantages stated in our presentation.

Q7: 25 students (68 %) answered that it is the law of energy conservation. 8 students (22 %) stated the gravitational law and four students wrote simply “gravity”. 5 students (14 %) mentioned the gravitational force (therefore students again confuse FORCE with LAW or maybe they do not distinguish between these two terms).

Q8: 26 students (70 %) wrote that the change (the planet is slowed down or planet’s distance from the Sun is changed or planet’s orbital period is longer) is negligible. That is the answer we expected. But we will have to reword the question, because we also got following answers which are correct – nevertheless we do not know whether students got the right idea about this problem. Six students (22 %) wrote that something was changed (the planet was slowed down or its distance from the Sun was changed) or they simply wrote just “Yes”. And 5 students (14 %) stated that nothing happens with the planet (which is also correct because the change is really negligible).

Q9: 14 students (38 %) wrote reaching Mercury or the Sun and 9 students (24 %) remembered probe’ insertion to the planet’s orbit. A considerable number of students, 14 (38 %), wrote that we have to slow
down the probe when we want to perform some measurements or taking detailed images – so in their case the Figures 4 and 6 were insufficient.

Q10: 10 students (27 %) were not interested in this topic or gave no answer. 9 (24 %) students expressed their interest in the topic but they will not look for more information. 13 respondents (35 %) think the topic is interesting and they will search for more data. Three students considered the topic interesting but they gave no answer about looking for information. Four students answered that the topic was interesting and because the lecture included all needed facts, they will not search for more information.

Conclusions

We prepared materials for the support of teaching the gravitational assist, especially velocity-time diagrams and animations of spacecraft flights. In this paper we presented three parts of the lesson about the gravitational assist: the right trajectory of a spacecraft in the Solar system, a slowing down of the spacecraft when flying to Mercury or to the Sun and four examples of velocity-time diagrams.

We presented our lesson three times, there were 37 students, who were given two questionnaires, one before the lesson and the other after it.

The questionnaire before the lesson primarily showed that this topic had not been known to students (66 % had not had heard about the gravitational assist and the others had heard only a short remark about it). Maybe this is the reason why students gave wrong answers to our questions. They probably confuse two important physical terms: force and law.

The questionnaire after the lesson showed better results, all facts presented during the lesson appeared in students’ answers. One question (Q8) will have to be expressed in a different way because we could not identify from students’ answers whether they understood the problem properly. For most of the students (73 %) this topic was interesting but only some of them (35 %) will search for more information.

Thanks to our findings we will improve our lesson about the gravitational assist and these facts will help us prepare our future main research about selected gravitational phenomena (not only about the gravitational assist).

References


Figure 1. Example of 2D animation of Cassini spaceflight. In the picture there are orbits of Mercury (orange), Venus (brown), Earth (blue), Mars (red) and the Sun (yellow point), the spacecraft (green), the date and the speed of the spacecraft related to the Sun. Various settings are possible, for example the background color can be changed (which is useful for different types of classrooms where we show our animations). The situation shown here is a few days before the second Venus gravitational assist. The orientation is such that the positive $x$-axis heads to the Vernal equinox and the origin of the frame of reference is the Sun.
Figure 2. Three possibilities for the spacecraft’s trajectory from the Earth to Jupiter. The orientation of the graph is the same as in the Figure 1. The scale of the diagram is in astronomical units. It is the last picture of the sequence of pictures where we give students more possibilities for the trajectory. Red trajectories are wrong, the right one is the green trajectory – a part of an ellipse. The green trajectory is real – it is the trajectory of Ulysses spacecraft from the Earth to Jupiter where it performed the gravitational assist.
Figure 3. The spacecraft’s passage from one orbit to another orbit. The original orbit is the blue one. According to the equation (1) the speed in the periheleion $v_1$ is bigger than in the aphelion $v_2$ (the same statement applies to $v_3$ and $v_4$). When we want to get closer to the Sun, we need an elliptical orbit with a shorter semi-major axis (red). From the equation (2) used in the aphelion $A$ we get the result: $v_3 < v_1$ (very surprising for students) which means that the spacecraft has to slow down.
Figure 4. A velocity-time graph of Galileo's speed relative to the Earth. The situation is for the Galileo probe's second Earth flyby. The time before and after the closest approach to the Earth is given in hours. Black points show its entry into and exit from the sphere of influence of the Earth. The graph is symmetrical – in our students’ opinion “too symmetrical”, so it is necessary to explain them that the data are real obtained from HORIZONS Web-Interface (Jet Propulsion Laboratory, 2012). From the diagram we can read that the speed before and after the flyby is the same (here it is the value of 8.92 km.s$^{-1}$). The speed of the spacecraft related to the planet is NOT CHANGED during the flyby.

Figure 5. A velocity-time graph of Galileo's speed relative to the Sun. The situation is for the Galileo's second Earth flyby (the same as in Figure 4), we have to point out to students that both graphs (Fig. 4 and 5) represent the same values but in Fig. 4 they are related to the Earth and here to the Sun. The time before and after the closest approach to the Earth is given in hours. Black points depict entry into and exit from the sphere of influence of the Earth. From the diagram we can read that the speed is increased, before the flyby the speed was 35.15 km.s$^{-1}$ and after it 39.04 km.s$^{-1}$, so the spacecraft was accelerated by 3.89 km.s$^{-1}$ thanks to the gravitational assist with the Earth. The speed of the spacecraft related to the planet is INCREASED during the flyby.
Figure 6. A velocity-time graph of Messenger’s speed relative to the Earth. The situation is for the Messenger’s Earth flyby. The time before and after the closest approach to the Earth is given in hours. Black points depict entry into and exit from the sphere of influence of the Earth. The graph is symmetrical – in our students’ opinion “too symmetrical”, so it is necessary to explain them that the data are real obtained from HORIZONS Web-Interface (Jet Propulsion Laboratory, 2012). From the diagram we can read that the speed before and after the flyby is the same (here it is the value of 4.16 km.s⁻¹). The speed of the spacecraft related to the planet is NOT CHANGED during the flyby. Compare this graph with the Figure 4. Students very often expect here a different shape – instead of the maximum they think there should be a minimum – that the spacecraft slows down when is approaching the planet and it speeds up when is departing from the planet (related to the planet).
Figure 7. A velocity-time graph of Messenger’s speed relative to the Sun. The situation is for Messenger’s second Earth flyby (the same as in Figure 6), we have to point out to students that both graphs (Fig. 6 and 7) represent the same values but in Fig. 6 they are related to the Earth and here to the Sun. The time before and after the closest approach to the Earth is given in hours. Black points depict entry into and exit from the sphere of influence of the Earth. From the graph we can read that the speed is decreased, before the flyby the speed was 29.47 km.s\(^{-1}\) and after it 25.42 km.s\(^{-1}\), so the spacecraft was decelerated by 4.05 km.s\(^{-1}\) thanks to the gravitational assist with the Earth. The speed of the spacecraft related to the planet is DECREASED during the flyby. Compare this graph with the Figure 5.
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Design, Implementation and Evaluation of Three-Dimensional Models in Autocad for the Understanding of the Maxwell Equations in Differential Form

J.P. Oviedo, Systems Engineering Program: Cooperative Group on Teaching and Interactive Experiences, Cooperative University of Colombia-Ibagué
G.A. Atehortua, Systems Engineering Program: Cooperative Group on Teaching and Interactive Experiences, Cooperative University of Colombia-Ibagué
D. Osorio, Systems Engineering Program: Cooperative Group on Teaching and Interactive Experiences, Cooperative University of Colombia-Ibagué
R. Marquez, Systems Engineering Program: Cooperative Group on Teaching and Interactive Experiences, Cooperative University of Colombia-Ibagué
S.Y. Lopez, Faculty of Education: Education Group in Experimental Sciences and Mathematics, University of Antioquia
A.A. Rojas,* Systems Engineering Program: Cooperative Group on Teaching and Interactive Experiences, Cooperative University of Colombia-Ibagué

*angel.rojas @campusucc.edu.co

Abstract

Physical concepts have Traditionally been difficult to understand for students faced in the process of it is formation on a subject related to the disciplinary field, however, there are some concepts which by their ability to be compared with real referents, maybe more understandable to students, but cannot say the same of those fundamental physical concepts that have a high degree of complexity for your understanding. Specifically, difficulties have been detected for students in the understanding of laws that contain the concept of field and flux, such as: Gauss’s Law (Electric and Magnetic Field), Ampere and Faraday’s law, but even when they are presented through a mathematical language based on vector and explicit relationships with partial derivatives (equations in differential form). The identification of these difficulties relate particularly to the understanding of the equations and their respective deduction will leads us to contemplate the need to propose strategies and tools that can be implemented in the classroom for the purpose of these topics in Physics become more accessible to our students. Trying to answer the question: ¿ what possible tools can be implemented to provide students with an understanding of Maxwell’s equations in differential form? Based on this guiding question was formulated a proposal aimed at teaching design, implementation and evaluation of three-dimensional models in AutoCAD, considered potentially significant materials from the perspective ausubelian (Ausubel, 2002), for the purpose of addressing the teaching of Maxwell’s equations in differential form in a course of Electricity and Magnetism. This proposal was based on the construction of conceptual and theoretical models (mathematical models) by some students of the course, with the continued support of the teacher. The main results of the implementation of this proposal, valued mainly from a qualitative perspective, show that AutoCAD becomes a highly potential tool for working with conceptual and theoretical models, allowing more interactivity from the construction of more complex representations in three dimensional formats. Thus favoring the understanding of physical concepts, specifically those related to Maxwell’s equations. Also generate a greater disposition of students to achieve meaningful learning of physics as a field of knowledge. We believe that implementing this type of such proposal are consolidated as a valuable contribution to the teaching of physics concepts that can be perfectly supported whit the use of Information Technology and Communication whit the great growing in the teaching and learning process.

Keywords: three-dimensional model, Maxwell’s equations, collaborative environment, AutoCAD
Introduction

Given that there are problems in understanding the physical concepts such as presented in traditional education would be important to explore new ways of organizing knowledge of physics, so that the learner understands the physical concept of field under two domains: the domain of mathematics and physics domain (Llancaqueo, A.; Caballero M. C. y Moreira, M.A., 2003). This allows us to think that it is possible to guide the process of building knowledge of the concepts and basic procedures of electromagnetic physics from the construction of models.

One of the most important and delicate in design and conception of the tools (conceptual models) is to achieve a description as close as possible of physical phenomena. These phenomena can be represented by theoretical models based on fundamental laws of electromagnetism, arranged in Maxwell’s equations. Assuming certain hypotheses is possible to obtain appropriate theoretical models to be represented from a specific tool, and can provide qualitative information and quantitative performance.

From a mathematical point of view, the estimation of these phenomena can be reduced to solving a system of partial differential equations with appropriate boundary conditions. However, the theoretical model of the analyzed tool should contain information on the “geometrical characteristics of the system, the electromagnetic characteristics of the environment where physical phenomena occur and field sources. The need to consider all these characteristics simultaneously limits the direct analytical solutions to simple cases with little interest in engineering. The analysis allows considering the complexity of the language experts as a source of epistemological obstacles in communication between teachers and students.

So, to learn the concepts of the fields are necessary for students to have created mental representations of them and, to this end, it is also indispensable have a good understanding the concepts behind the fields. Classroom reality shows that conceptual obstacles that prevent adequate generation of mental representations over fields and, consequently, not achieved significant learning.

In this paper, we consider the tools (three-dimensional models) as “concrete representations” as opposed to “instrumental representations” that are obtained by signals from scientific equipment or devices. It also marks a fundamental difference between “mental model” and “conceptual model”: it is proposed that a mental model is a set of ideas in the minds of people, while the “conceptual models” should be tools for understanding and / or teaching of physical systems, and also representations necessarily shared by a particular community. These representations are materialized in the form of mathematical formulations.

Theoretical framework

To appropriate a concept and build knowledge people make use of representations or mental models. These schemas are generated to capture, understand and predict phenomena. Learning is directly related to the approach of varying mental representations generated scientific models of the phenomenon in question. People do not apprehend the world directly, but have an internal representation of it, says Johnson-Laird and proposed this author considers the fundamental principle of cognitive science that postulates the mind as a symbolic system that can build symbols and manipulate in various cognitive processes, assuming the psychological essence of understanding is to have in mind a “working model” of the phenomenon referred. This leads us to think that the type of model that generates a person in respect of a particular event or concept would be related to the degree of familiarity that one has of the event.

According to Johnson-Laird (Johnson-Laird, P., 1996) from cognitive psychology, humans do not know directly “reality”, but reconstructed from the mental models that allow us to interpret what we perceive. These mental models include propositional representations and images, respectively. These models are the views that people have of the world, of themselves, of their own abilities, of what others expect of them. Mental models are formed in the interaction with the environment and with others, have predictive and explanatory power.

According to Moreira et al (2003), since the teaching of science, mental models allow individuals to understand phenomena, make inferences and predictions, decided to take action and monitor their implementation. It is built working models in the field of knowledge of a discipline. These authors also
note that “conceptual models” should be considered as those designed for scientists, engineers, teachers to facilitate the understanding and teaching of physical systems, or states of physical things, or natural phenomena. According to these authors, the conceptual models would be tools for understanding and / or teaching of physical systems, and also representations necessarily shared by a particular community, consistent with scientific knowledge that this community has. These representations have the quality to be external and therefore come in the form of mathematical formulations, verbal or pictorial analogies or material artifacts.

Considering models as essential elements of scientific knowledge, it is necessary to refer to the epistemological view we have of them [1]. Critical stance that assumes Bunge (1972) concerning science breaks with a dogmatic, taking science as a rational process, but also creative, what is known as critical realism, and that implies the need to acquire theoretical knowledge to enrich our apprehension of the world. Since this is the essence of scientific modeling perspective bungeana.

His conception of science from a rational perspective and realistic involves critical and non-dogmatic conception of scientific knowledge in the same way that sees science as a creative process. This author stresses the active role of the subject and considers building conceptual models and theoretical models as a creative activity that jeopardizes the knowledge, preferences and even intellectual passion constructor (Bunge, M., 1972).

The models that are built Bunge referenced as explanations of the world and with the express purpose of capturing the reality and representations are assumed simplified and idealized of reality and not reality itself. The process of construction of such models is what is meant as scientific modeling bungeana perspective, considering that all scientific models helps to optimize the understanding of reality, the apprehension of the world.

The models that are referenced Bunge conceptual models and theoretical models as hypothetical schemes supposedly real things and events. Thus, a conceptual model is treated as an object-model concerning supposedly real objects and aims to provide a symbolic image of reality (Bunge, M., 1972). The object-model is idealized and abstracted human creations of real objects or actual cases and only partially represents objects or facts to which they refer.

All previous considerations lead us to propose a theoretical framework in which the images, sketches, models and many other teaching resources expressed in graphic language are considered as the “representations-concrete” being employed an expert (teaching or research) to explain part of his conceptual model. That is, the concrete representations would be just a graphical part of the “conceptual model” that, additionally described in different languages, allows the expert to express complex mental model that harmonizes your ideas.

**Methodology**

This study is the analysis of an educational experience. This experience was planned and tried to implement seeking to answer both intrinsic interest, in improving the teaching practice of the author, who was the teacher of the participating students, as extrinsic interests consistent with creating tools modernity (ICT) and helpful for the education community. To carry out this research we chose to use a qualitative methodology that was part of the paradigm type sociocritic and was participatory action research as a form of self-reflective research, where participants are intended to improve their own educational practices (Kemmis, S., 1984). In this research made use of semi-structured interviews to understand the problems that students have to model the phenomenon scientifically field and flux. Then apply a test (Llancaqueo, A.; Caballero M. C. y Moreira, M.A., 2003) to evaluate management concepts and mathematical models inherent in these phenomena. The instruments were applied to 10 students, whose ages ranged between 17 and 19 years who attended the course of Electricity and Magnetism. With the instrument mentioned was possible to collect data on certain topics that affect mental representations that form students.

Specifically, they proposed to students, divided into three groups, two of three and one of four, design a three-dimensional model for Faraday’s law, which would allow us to understand the mathematical model in differential form. Furthermore, they had to write a report after the completion of the design. Our

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interests is rather the development of tools and through them construct models, frameworks, patterns or interpretations useful for researchers or teachers in contexts with common characteristics and similar interests.

**3D Model (AutoCAD)**

Selected tools were designed in AutoCAD and through them and taking into account the experimental laws of electricity and magnetism are summarized in a series of expressions known as Maxwell’s equations. These equations relate the electric field vectors (E) and magnetic induction (B), with its fountains, which are electric charges, currents and variable fields, the concepts of electric flux, magnetic, electromagnetic induction.

The fields E and B are determined by the positions of the charges and their movements (or current), which is why they are called sources of the electromagnetic field, as known them through Maxwell’s equations we can calculate E and B. as we have seen, we can deduce the mathematical models for the Maxwell equations in differential form.

**1 Maxwell’s first law or Gauss law for the electric field**

Gauss’s law is one of the fundamental laws of electromagnetic theory; it is a relationship between the charge contained in a surface and flow of its electric field, through it, becoming a means to obtain expressions of fields electric, with sufficient symmetry conditions.

One of the most important laws, which are part of the laws of Maxwell, Gauss’s law. This law allows to easily find the electric field, so extremely easy to charged bodies geometrically regularly. This law can be applied to surfaces of any shape. In this we applied to the surface surrounding an infinitesimal volume of edges parallel to the axes XYZ, as illustrated in Figure later. The sides of the elementary volume element are dx, dy and dz.

**Figure 1.** Representation of three-dimensional model in AutoCAD to Gauss’s law for the electric field.

**2 Second Law of Maxwell or Gauss law for the magnetic field**

The magnetic flux through a closed surface is always zero. Since there is no magnetic masses or poles insulated where dipoles are formed, then the B field lines are closed. That is, the incoming flow through any closed surface is equal to the outgoing flow.
3 Third law of Maxwell or Faraday’s law – Henry

A time-dependent magnetic field implies the existence of an electric field, such that its circulation along a closed path is equal arbitrary unless the derivative with respect to time of magnetic flux through a surface bounded by the path. This surface is not closed, and therefore the magnetic flux passing through it need not necessarily be zero.

This law describes as \( E \) lines are surrounding an area where the magnetic flux passing through it, is changing. The law of electromagnetic induction according saw can be applied to roads anyway. Consider an infinitesimal rectangular path on the XY plane PQRS.

\[
\int_{\text{PQRS}} \vec{E} \cdot d\vec{l} = \int_{\text{PQ}} E \cdot dl + \int_{\text{QR}} E \cdot dl + \int_{\text{RS}} E \cdot dl + \int_{\text{SP}} E \cdot dl
\]

\[
\int_{\text{QR}} E \cdot dl \cos \theta = Ey \ dy \quad \int_{\text{SP}} E \cdot dl \cos \theta = -E'y \ dy
\]
Since the distance between PQ is very small (dx), then the variation of the field
\[ \Delta E = (E_y - E_y') \text{d}E_y \]

Similarly,
\[ \int_{PQ} E \, dl \cos \theta + \int_{RS} E \, dl \cos \theta = (E_y - E_y') \, dy = \frac{\partial E_y}{\partial x} \, dx \, dy \]

The sum of the four integrals worth:
\[ \int \vec{E} \cdot d\vec{l} = \int_{PQ} E \, dl + \int_{QR} E \, dl + \int_{RS} E \, dl + \int_{SP} E \, dl = \left( \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} \right) \, dx \, dy \]

Furthermore, the flow through the surface is:
\[ \phi_{PQRS} = \int_S \vec{B} \cdot d\vec{s} = B_z \, dx \, dy \]

Substituting in the expression of the Faraday-Henry Law gives:
\[ \int_{L} \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \int_{S} \vec{B} \cdot d\vec{s} \]

Obtained:
\[ \left( \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} \right) \, dx \, dy = -\frac{d}{dt} (B_z \, dx \, dy) \rightarrow \frac{\partial E_y}{\partial x} \cdot \frac{\partial E_x}{\partial y} = -\frac{\partial B_z}{\partial t} \]

Placing the infinitesimal rectangle YZ and XZ planes:
\[ \frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial z} = -\frac{\partial E_x}{\partial t} \quad \gamma \quad \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -\frac{\partial B_z}{\partial t} \]

The combination of these three expressions give Faraday’s law in differential form can be written as:
\[ \text{Rot} \, \vec{E} = -\frac{\partial \vec{B}}{\partial t} \]

Which is to say: \[ \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \]

Similarly, we can use the model in AutoCAD to develop Ampere law, Could show all the equations, but is not the purpose of this paper.

Results and conclusions

Most students demonstrated to have developed a proper understanding of the nature and use of conceptual model (tool), as well as about the importance of process modeling in the construction of scientific knowledge. This was evident in the various discussions that took place and attitude in different stages of design, development and reflections of the same when asked about these issues.
Most of the students were able to develop and reformulate their models. These observations support the conclusion that the teaching strategy used favored student learning.

Importantly too the contribution of the teacher to have a positive impact on students, cognitively and emotionally involving them in activities. This is an aspect that we consider essential for learning to occur.

The research showed us that students who have an interest in science in general are a minority, and even for them learning difficulties are enormous. According to the observations we can infer that students have difficulties in the implementation of differential and integral calculus in other contexts. We believe that a context of classroom research as close as possible to a real scientific research context can provide a platform for the acquisition of scientific skills such as writing articles using criteria scientists because, in that situation, the acquisition of those skills makes sense for students.

The results of this study indicate that the improvement of learning and scientific writing is possible by practice supervised by the teacher. The contexts of construction tools (conceptual models) working in small groups allow the progress of the students in a typical aspects of scientific culture, but the assistance provided by the teacher, conceived as scaffolding has been key.

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Teaching Physics and Mathematics for Earth Sciences with Computational Modelling

Rui G. Neves, Unidade de Investigação Educação e Desenvolvimento (UIED) & Departamento de Ciências Sociais Aplicadas (DCSA), Faculdade de Ciências e Tecnologia (FCT), Universidade Nova de Lisboa (UNL), Portugal
Maria C. Neves, Instituto D. Luiz (IDL) & Faculdade de Ciências e Tecnologia (FCT), Universidade do Algarve (UAlg), Portugal
Vítor D. Teodoro, Unidade de Investigação Educação e Desenvolvimento (UIED) & Departamento de Ciências Sociais Aplicadas (DCSA), Faculdade de Ciências e Tecnologia (FCT), Universidade Nova de Lisboa (UNL), Portugal

Abstract

Modern research and other professional activities in many earth sciences areas require advanced knowledge about mathematical physics models and scientific computation methods and tools. Learning such advanced knowledge skills is a difficult cognitive process that progressively should bring up a strong background in physics, mathematics and scientific computation that is appropriately adjusted to each different area of the earth sciences. At introductory levels, from secondary education to the first two years of university education, the corresponding earth sciences learning environments should then be based on curricula that balance the integration of interactive engagement sequences of computational modelling activities, created with computer modelling systems which give students the opportunity to improve their knowledge of physics, mathematics and scientific computation, while simultaneously focusing learning on the relevant earth sciences concepts and processes. In this paper we discuss the application to this context of exploratory and expressive computational modelling activities implemented in the Modellus environment. To illustrate, we describe a sequence of activities about the blackbody radiation laws implemented in undergraduate university introductory meteorology courses involving students possessing only very basic secondary education knowledge about physics and mathematics and no significant prior knowledge about scientific computation. We show that students were able to create and explore the proposed mathematical physics models and simulations, establishing meaningful and operationally reified relations with the appropriate meteorological phenomena. The activities also show that introductory learning processes of models can involve differential equations solved by simple numerical methods and that students are able to appreciate the differences between numerical solutions and analytical solutions. We also show that students reacted very positively to the activities, considering them to be important in the context of earth sciences courses and professional training, as well as to Modellus, considered user-friendly and helpful for meaningful learning processes of mathematical physics models.

Introduction

Physics and mathematics are important subjects for the development of knowledge in the earth sciences and related industrial or technological fields. Their modern epistemologies, much like those of the earth sciences and also of other areas of science, technology, engineering and mathematics (STEM), involve interactive modelling processes that balance different elements from theory, scientific computation and experimentation.

However, the majority of current introductory physics and mathematics courses in STEM areas continue to be unable to reflect this range of epistemological characteristics. For example, introductory physics courses at university level, even when well equipped with modern facilities, are usually based on expositive theoretical lectures, recipe experimental laboratories and problem solving classes, and cover superficially a very large number of topics. The use of computational methods and tools, for instance, is largely limited to the simple display of text, images and simulations, or to a supporting role in data acquisition and analysis. In general, these courses are considered too difficult and disappointing by many students and have low exam success rates. Also, many students acquire a fragmented knowledge of physics and mathematics.
with numerous conceptual and reasoning weaknesses which persist after they pass their examinations (Halloun & Hestenes, 1985a, 1985b; McDermott, 1991). Furthermore, average student expectations about physics decrease after completing this type of courses (Redish et al., 1998). Similar learning problems within the earth sciences have also been documented (Libarkin & Anderson, 2005).

To change this situation introductory physics and mathematics curricula and learning environments should be based on pedagogical methodologies inspired in the modelling processes of physics and mathematics research, taking care to define specific strategies for each STEM area, to help students establish epistemologically balanced learning paths through the different cognitive phases of the various types of modelling processes. This is an expectation supported by the results of many research efforts in various contexts (see, e.g., Blum et al., 2007; Handelsman et al., 2005; Kortz et al., 2008; McConnell et al., 2006; McDermott & Redish, 1999; Meltzer & Thornton, 2012; Slooten et al., 2006), which have been able to show that the learning processes can effectively be enhanced, when students are embedded in environments with activities that approximately recreate the cognitive involvement of scientists in modelling research experiences. As opposed to traditional instruction, which for many students ends up reducing learning to a rote accumulation of fragmented facts or rules, these interactive engagement approaches have shown to be able to motivate students for interactive learning processes that lead to better knowledge performance, and are more effective in resolving cognitive conflicts with common sense beliefs or incorrect scientific ideas.

In many earth sciences areas, such as for example geophysics and meteorology, professional modelling actions require knowledge about advanced mathematical physics models which are rich in computational elements. For students, learning such advanced knowledge skills is a difficult cognitive process that should progressively bring up a strong background in physics, mathematics and scientific computation, in a way that should be appropriately adjusted to each different area of the earth sciences. At an introductory level, from secondary education to the first two years of university education, when this background is still forming, the corresponding learning environments should then be based on curricula that balance the integration of interactive engagement sequences of computational modelling activities, created with computer modelling systems which give students the opportunity to improve their knowledge in physics, mathematics and scientific computation, while simultaneously focusing learning on the relevant earth sciences concepts and processes.

A key feature of these curricula, and of similar ones in other STEM areas, should be to introduce scientific computation effectively controlling the cognitive load associated with operational notions of programming and specific software knowledge. Such is difficult to achieve with professional languages like Fortran (Bork, 1967), Pascal (Redish & Wilson, 1993), Java (Gould et al., 2007) or Python (Chabay & Sherwood, 2008), professional scientific computation software such as Mathematica or Matlab, or even with educational programming languages like Logo (Papert, 1980) or Boxer (diSessa, 2000) because these languages require that students acquire a working knowledge of programming along with knowledge about the specific STEM themes covered. To avoid this problem several computer modelling systems have been developed over the years, for example, the DMS (Ogborn, 1985), Stella (Richmond, 2004), Coach (Heck et al., 2009), EJS (Christian & Esquembre, 2007), Modellus (Teodoro & Neves, 2011) and PhET simulations (Wieman et al., 2008).

Our approach in this context has involved the integration of interactive engagement learning activities built around computational modelling experiments implemented in the Modellus environment (see, e.g., Neves et al., 2012; Neves et al., 2011, 2010; Neves & Teodoro, 2010; Teodoro & Neves, 2011). Several action research tests were conducted in general physics and biophysics courses of biomedical and informatics engineering university majors at FCT/UNL, showing that Modellus can be a particularly useful system to limit the level of programming and specific software overhead in interactive computational modelling activities conceived to teach introductory physics and mathematics. The main Modellus functionalities supporting this success were: 1) An easy and intuitive creation of mathematical models using standard mathematical notation; 2) The possibility to create animations with interactive objects that have mathematical properties expressed in the model; 3) The simultaneous exploration of multiple representations such as images, tables, graphs and animations; and 4) The computation and display of mathematical quantities obtained from the analysis of images and graphs.
With this Modellus features it was possible to create interactive learning activities that spanned the range of different kinds of modelling from explorative to expressive modelling (Bliss & Ogborn, 1989; Schwartz, 2007), addressed several cognitive conflicts in the understanding of physics and mathematical concepts, allowed manipulation of multiple representations of mathematical models and the interconnection between analytical and numerical approaches. With simple numerical methods, the analysis of more realistic problems was also possible at an earlier learning stage. An illustrative example is the interactive modelling of a long jump on the computer screen by first year university biomedical engineering students (Neves et al., 2012).

The qualitative results of these actions indicate that the physics and mathematics learning and teaching processes are indeed improving with our interactive computational modelling approach. In this paper we extend this research to the different STEM context of earth sciences education and discuss the application of our approach in teaching introductory physics and mathematics with scientific computation to earth sciences students.

Teaching organization and methodology

Let us start with a brief description of the main aspects related to the teaching organization and methodology used for an effective application of our approach. The specific action research setting we considered for the earth sciences education context was that of introductory meteorology courses, gathering in each academic year an average of 50 second year undergraduate university students mainly from FCT/UAlg environmental engineering, marine sciences and biology degrees. All these students had only very basic secondary education level knowledge about physics and mathematics and no significant prior knowledge about scientific computation.

The introductory meteorology courses we considered for our field actions are divided into three complementary components: lectures where the theoretical foundations are first introduced, paper and pencil problem-solving lessons, and the computational modelling classes based on Modellus. To build an interactive engagement environment students are organized in group teams of two or three. During each computational modelling class, the teams work on a set of activities, all of which are to be completed using only Modellus as computer modelling tool. These activities are designed to be interactive and exploratory learning experiences structured around specific topics and aim to set up an atmosphere for meaningful learning (see, e.g., Mintzes et al., 2005) where students approximately work as scientists do in modelling research activities. In particular, the computer, and its associated powerful calculation, exploration, visualization, simulation and validation capabilities, is to be used as a cognitive artefact to enhance student cognitive activity during modelling and aim at improved familiarization and reification processes (Teodoro et al., 2012).

In class the student teams are motivated to analyse, discuss and solve the proposed activity problems on their own using the physical, mathematical and computational modelling guidelines provided by the class documentation and software resources. These activities are appropriately articulated with the complementary theoretical and paper and pencil problem solving classes. Note that the teams are not left working alone but continuously helped during the exploration of the activities to ensure an adequate working rhythm with appropriate conceptual, analytical and computational understanding. Whenever necessary, global class discussions are conducted to keep the pace, to introduce new themes, to clarify any doubts on concepts, reasoning or calculations common to several teams and for student work presentations.

The supporting class documentation and software resources for the courses we have implemented included Modellus package examples and a set of activity PDF documents. For most of the class activities these PDF documents contained complete step-by-step instructions to build the Modellus mathematical models, animations, graphs and tables. However, some activities, including those for assessment, involved computational modelling problems with instructions having various challenging degrees of incompleteness. The assessment procedures involved continuous group and individual evaluation based on the regular class activities and homework assignments. At the end of the courses, students answered a questionnaire, not counting for the final grade, to evaluate their perceptions about Modellus and the interactive computational modelling activities.

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Interactive computational modelling activities: Blackbody radiation laws

To illustrate the type of interactive computational modelling activities we have implemented with Modellus to teach physics and mathematics in the introductory meteorology courses, consider an example about the blackbody radiation laws. This example shows the use of graphical representations and numerical integration, and explicitly takes into account that students have only very basic secondary education level knowledge about physics and mathematics and no significant prior knowledge about scientific computation.

The laws for blackbody radiation are a standard introductory physics topic applied, for instance, to the study of energy transfer in the Earth’s atmosphere. In this computational modelling activity students are proposed an interactive exploration of Planck’s law for the radiation power density function leading to Wien and Stefan-Boltzmann laws.

The starting step (see Figure 1) is to write in the Modellus Mathematical Model window the radiation power density function $B(\lambda)$ which is given by

$$B(\lambda) = \frac{2\pi hc^2}{\lambda^5 \left( \frac{hc}{\lambda kT} - 1 \right)}.$$  

where $\lambda$ is the radiation wavelength, $h$ is Planck’s constant, $c$ is the speed of light, $k$ is the Boltzmann constant and $T$ is the temperature. The parameters $h$, $c$, $k$ and $T$ are defined in the Parameters ribbon (see Figure 1). The radiation wavelength is chosen to be the independent variable and the next step is to define in the Independent Variable ribbon the adequate domain interval for $\lambda$. This provides an opportunity for students to verify the range of values relevant for atmospheric radiation, in particular, the visible (solar) and infrared (terrestrial) radiation intervals. In the same ribbon students can also define the numerical step $\Delta \lambda$ associated with $\lambda$. The following step is to represent $B(\lambda)$ in graphical form using the Graph window. In figure 1 we show a Graph window with 3 different curves corresponding to 3 different temperature cases, $T = 300$ K, $T = 400$ K and $T = 500$ K. Figure 1 also shows the Table window where the values used to draw these curves can be explicitly displayed in table form.

One of the advantages of using numerical solutions is to give introductory level students the opportunity to deduce Wien and Stefan-Boltzmann laws without having to perform the corresponding analytic derivations which are beyond the learning scope of most introductory courses. To deduce Wien displacement law students start by selecting one of the graphs representing $B(\lambda)$ for a certain value of the temperature $T$, for example, $T = 400$ K (see Figure 2). Selecting Tangent Lines in the Graph ribbon and using the mouse to move it along the graph, it is possible to visualize the tangent at every point along the curve and read in the abscissas axis the value of $\lambda$ for which this tangent is horizontal. At this point $\lambda_{\text{max}} = 7.26\times10^{-6}$ m, the radiation power density attains its maximum value $B(\lambda_{\text{max}}) = 1.31\times10^8$ W/m$^3$. Students can then compute the product $\lambda_{\text{max}} T$ and verify that the numerical result is approximately equal to the theoretical value of Wien’s constant, $c_w = 2.898\times10^3$ mK. Students can interactively check that the fit between the computed and the theoretical Wien constant is improved when a smaller numerical step $\Delta \lambda$ is used, and also that Wien’s law is similarly obtained using another $B(\lambda)$ curve for a different value of $T$.  

WCPE 2012, Istanbul, Turkey
Figure 1. Modellus blackbody radiation model showing in the Mathematical Model window Planck’s radiation power density function $B(\lambda)$ and its numerical integration over the wavelength $\lambda$ which leads to Stefan-Boltzmann law for the power radiated per unit area $E$. Also shown are the Graph window with 3 curves for 3 different temperatures, $T = 500$ K (orange), $T = 400$ K (green) and $T = 300$ K (cyan), the Table window and the Animation with a Pen object showing the graph of $E$ as function of $\lambda$ and a Variable $ESB$ displaying Stefan-Boltzmann limit $\sigma T^4$ for $T = 500$ K.

Finally, to deduce Stefan-Boltzmann law students use numerical integration to show that the power radiated per unit area $E$ satisfies

$$E = \int_0^{+\infty} B(\lambda) d\lambda = \sigma T^4,$$

where $\sigma = 5.67 \times 10^{-8}$ W/(m$^2$K$^4$) is the Stefan-Boltzmann constant. The integration is programmed in the Mathematical Model window using the instruction (see Figure 1)

$$E = \text{last}(E) + B \times \Delta \lambda,$$

with the initial condition $E = 0$. This is an application of the trapezoidal rule, a simple and useful numerical method for students just starting an introduction to scientific computation. The result of the integration can be visualized creating a Variable object $ESB$ (see Figure 1) or plotting the graph of $E$ as a function of $\lambda$. In figure 1 we show this graph as it is created by a Pen in the Animation area. The curve represents the accumulated area below $B(\lambda)$ as $\lambda$ runs through its domain and students can verify that it approaches a constant value approximately equal to the product $\sigma T^4$. 
Field actions discussion and conclusions

In this paper we have shown how Modellus can be used to develop interactive computational modelling activities that introduce mathematical physics models of interest in earth sciences contexts, to students with only basic secondary level knowledge of physics and mathematics and no prior knowledge of scientific computation. As an illustrative example, with insights on Modellus functionalities and potentialities for computer-assisted teaching and learning, we have described an activity about the blackbody radiation laws. This and other computational modelling activities have been field tested in introductory meteorology courses we have implemented for first cycle undergraduate university students at FCT/UAlg.

As shown by the average results of Likert scale questionnaires given at the end of each meteorology course (see Figure 3), the majority of students reacted very positively to the computational modelling activities. For example, defining the average opinion of a student as the average over all answers given by the student to the questionnaire statements, the results obtained for the 2011 edition of the introductory meteorology course showed that 95% of the students had a positive opinion, averaging 1 (30%), 2 (54%) or 3 (11%), 5% averaged no preferred opinion, and none of the students averaged a negative opinion. Students considered the activities useful for the learning processes in meteorology and for their professional training as a whole. In addition, Modellus was considered easy to learn, user-friendly and helpful for meaningful learning processes of mathematical physics models. The PDF documents used to present the activities were considered interesting and well designed. Students also considered favourably working in interactive engagement groups and using Modellus in other earth sciences subjects with appropriately adapted computational modelling activities.

Figure 2. Modellus graphical deduction of Wien’s displacement law using a tangent line to the $T = 400$ K Planck density curve. To move the tangent line along the curve select and hold down the left mouse button or drag the Independent Variable button in the Animation Control bar. To select the curve maximum increase the number displaying precision selecting at least 5 decimal places in the Home ribbon. Then use the One step back or One step forward buttons and check the values in the Table window.

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1. Introducing the computational component in the learning process was useful for your professional training.

2. The relative time percentage given to the computational classes was adequate.

3. Introducing the computational component was useful for the learning process of Meteorology.

4. Doing the activities in groups of 2 or 3 has more advantages than doing the activities individually.

5. During classes, the teacher’s guidance and support to the several groups was sufficient and adequate.

6. The problems analysed in the computational activities with Modellus were interesting and motivating.

7. The activities with Modellus in PDF format are well conceived and interesting.

8. Modellus is a useful software to help the learning of mathematical-physics models.

9. Modellus is easy to learn and is user-friendly.

10. Modellus could be used in other disciplines of your course, with adequate activities.

Figure 3. Introductory meteorology questionnaire and results for the 2011 course edition. For each questionnaire assertion the Likert scale starts at -3 and ends at +3, -3 stating complete disagreement, +3 complete agreement and 0 no preferred opinion. The bar graph shows the Likert scale distribution of the average student opinion per questionnaire assertion.

On the other hand, content analysis of student coursework and evaluation tests has shown that the interactive computational modelling activities with Modellus and associated PDF documents were successful in identifying and resolving many student difficulties in aspects of physics, mathematics and scientific computation relevant for the meteorology course. In the 2011 edition the average grade was 70% and of the 53 students involved only 3 were not able to pass on the computational modelling component. The PDF documents proved to be very useful to explain the fundamental modelling ideas, problem solving processes and challenges to solve as well as to help students overcome more rapidly the initial difficulties of using Modellus. Students were able to create and explore the proposed mathematical physics models and simulations, establishing meaningful relations with the appropriate meteorological phenomena and operationally reifying many mathematical objects they previously considered worthless. To have real time visible correspondence between the animations with interactive objects, graphs, tables and the mathematical model, with the opportunity to manipulate comparatively these different representations were again fundamental factors to achieve this. For example, the easy to draw Planck radiation curves helped students to better associate temperature with radiation emission and doing so by themselves constituted an extra motivation for learning. Student class performance and results on the activities also showed that introductory learning processes of mathematical physics models can involve differential equations solved by simple numerical methods and that students are able to appreciate the differences between numerical solutions and analytical solutions. The interactive engagement computational modelling activities with Modellus were thus successful in introducing mathematical physics models and scientific computation methods relevant for the earth sciences, helping students be better prepared for a posterior more advanced application of professional software systems or programming languages.
Future research will involve linking Modellus and other computer modelling systems, the development of new interactive digital documentation and software resources for earth sciences interactive engagement computational modelling activities, and new field research actions to test the new resources and analyse the corresponding learning and teaching processes.

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A High School Teaching/Learning Sequence On Normal Modes

M. Giliberti, Dipartimento di Fisica, Università degli Studi di Milano, via Celoria 16, 20133 Milano, Italy
E. Rigon ISIS, “Daniele Crespi”, Busto Arsizio, Italy
M. Stellato, Dipartimento di Fisica, Università degli Studi di Milano, via Celoria 16, 20133 Milano, Italy
M. Tamborini, Dipartimento di Fisica, Università degli Studi di Milano, via Celoria 16, 20133 Milano, Italy

Abstract

The physics education research group of the University of Milano has been working for many years to the implementation of teaching/learning sequences in quantum physics. Within this path a major importance is given to normal modes of oscillating systems seen as building tokens for understanding waves phenomenology. At this aim a specific didactic path on this topic has been implemented. We report here on two experimentations led in the course “Waves”, within the framework of “Milan Open Labs” of PLS (Scientific Degree Plan). We describe the teaching/learning sequence on normal modes and show some of the experiments that have been performed. Some preliminary results on the students response are briefly discussed.

Keywords: normal modes, lab activities, oscillations, waves, videos

1. Introduction

In the Italian upper secondary school normal modes are not commonly afforded and most of the Italian physics textbooks don’t even treat the topic. Moreover, in literature it is difficult to find but few examples of teaching normal modes to high school students, particularly if we look for an analysis of disciplinary knots and learning problems. Nonetheless, we think that normal modes represent a crucial issue for the understanding of important topics such as quantum physics, superconductivity and waves. For this reason we think they should be treated in the secondary school curricula.

The path we developed has been proposed to two different groups of high school students and was entirely based on an experimental approach with the support of two different data logging systems, a commercial one and a freeware one, namely the Vernier Logger Pro system (www.vernier.com/products/software/lp/) and the Tracker video analysis software (www.cabrillo.edu/dbrown/tracker).

2. The experimental context

The path on normal modes has been experimented in two different contexts. The first experimentation regarded thirty students participating, together with their teachers, to the “waves” extracurricular course in the framework of “Milan open labs” of PLS (Scientific Degrees Plan). PLS is a national Italian project funded by the Ministry of Education and created to promote collaboration between secondary school and University in order to increase the interest of young students for science. The PLS students were all high school students in scientific curriculum, some attending the fourth year, some the fifth (last) year. They all were well trained in trigonometry, in solving equations and some of them also in basic calculus. They had already studied topics on waves.

The second experimentation regarded nineteen students of a language school, during curricular lessons. All these students attended the fourth year. They had a poor mathematical background: they were not well trained in trigonometry, not even in quadratic equations and did not know basic calculus. They had never studied waves nor oscillations.

3. The teaching/learning sequence

The teaching and learning sequence was based on a set of different experiments starting from simple harmonic oscillations to end with normal modes of complex systems. The experiments were supported by the use of data logging, video analysis and applet simulations (www.falstad.com/mathphysics.html, www.fisicaondemusica.unimore.it). Taking videos of the experiments itself resulted particularly useful. In fact it allowed students to highlight specific details that are difficult to grasp by the naked eye, thanks to the use

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of image magnification and slow motion.

The main topics of the lessons were: the harmonic oscillator, normal modes of discrete systems in one dimension: coupled oscillators (mass-spring systems, coupled pendulums and Shive machine), normal modes of a continuous system (the vibrating string) and normal modes in two dimensions (Chladni plates).

Figure 1. the sequence

The sequence structure is shown in Fig.1. Each topic was introduced starting from a brainstorming in the form of interview where the teacher/interviewer tries to understand student’s individual conceptions as it is foreseen in teaching experiment design (Komorek Mand Duit R., 2004).

Each item was introduced by an experiment. The experiments were filmed and registered for further analysis. In some cases, additional videos from the net and applets simulations were performed. A quantitative investigation was often made possible by using the Logger Pro data acquisition system, as reported below. Video recording of the experiments not only made possible to investigate details invisible to the naked eye but also allowed students to perform motion analysis via video-tracking.

Each experiment was followed by a discussion in the form of interview as described above.

The next step was the repetition of the experiment and its implementation by the students divided in groups, with guided enquiry suggestions and peer discussion.

A final general discussion was performed.

A questionnaire was given to students long after (few weeks) to verify the effectiveness of the sequence. Due to the preliminary nature of the study, only qualitative research methods were used to analyse the data (Erickson F., 1998).

4. The data acquisition setup

The data acquisition system consists of The Vernier motion detector2 connected to the Vernier A/D converter interface “LabPro”. The interface is connected to a PC and the system is driven by its dedicated software, namely “Logger Pro”. Up to two digital sensors can be connected to LabPro.

All needed data analysis can be performed online with Logger Pro software.
Figure 2. the experimental setup

This Motion Detector emits short bursts of ultrasonic sound waves from the gold foil of the transducer. These waves fill a cone-shaped area about 15° to 20° off the axis of the centerline of the beam. The range of detection spans between 0.150 - 6.000 meters with a resolution of 0.001 meters.

The interface resolution is 12 - bit and maximum sampling rate is 50,000 samples per second.

In our plots the uncertainty bars are not shown because they have the same size of dots.

5. The experiments

The harmonic oscillator

This is the classic harmonic oscillator (Fig. 3) in the version of a mass vertically appended to a spring. The vertical configuration allows to avoid the problem of the friction with surfaces. The choice of the mass is such as to have a stable vertical oscillation, that is: the system has an almost linear behaviour and there is no coupling between vertical spring mode and transverse pendulum mode (M. G. Olsson, 1976) (it is interesting to show how the two modes of oscillations become resonant when a mass is chosen such that the spring oscillation frequency doubles the pendulum oscillation frequency).

Quantitative measurements are made by using Vernier Logger Pro data acquisition system. The setup used for this experiment is shown in Fig. 2.

The data acquisition system measures the mass position as a function of time. A sonar detects the position of the target object sending sonic pulses and detecting reflections. The sonic pulses are emitted at regular time intervals and the student can set the sampling frequency. The program can plot the waveform of position vs time, the velocity vs time and the acceleration vs time. In addition it is possible to plot the FFT (Fast Fourier Transform). The FFT function is given to students as merely “a button to push”, since upper secondary school students just need to know that this software extracts frequencies from waveforms.

Figure 3. the simple harmonic oscillator
With this equipment the students can compare the waveforms of position vs time and acceleration vs time. They can observe that at each time the acceleration is opposite to the displacement as required by the harmonic motion (R. Fitzpatrick, 2011. H. Georgi, 2007. S. R. Barbieri, M. A. Giliberti, 2012. F. S. Crowford Jr., 1968) (see Fig. 4). From graphics analysis and from FFT, students can also verify that, in this motion configuration, the oscillations frequency (or the period) does not depend on the waveform amplitude (R. Fitzpatrick, 2011. H. Georgi, 2007. S. R. Barbieri, M. A. Giliberti, 2012. F. S. Crowford Jr., 1968) (see Fig. 5). In fact, while the amplitude of the oscillation decreases due to the air friction, the frequency does not change.

The coupled oscillators (mass-spring systems)

The system consists of two up to four masses coupled by identical springs as shown in Fig. 6. The chain is disposed vertically for convenience as explained before. The upper end is bound to a T-rod while the lower end is bound to the pivot of an electromechanical vibrator (Pasco SF-9324 model). The vibrator is coupled with a sine wave generator (Pasco WA-9867 model) to be frequency tunable with 0.1 Hz resolution in the range from 0.0 to 800.0 Hz.

Figure 4. from left to right, position vs time and frequency plot: while the amplitude decreases because of friction, the frequency does not change

Figure 6. the mass-spring system
The students were asked to try and guess in how many ways the system could oscillate when excited by the vibrator and to find out some “special ways of movement”. Most students were able to identify the two normal modes regarding the two masses and three springs system. On the contrary, most students found difficult to predict normal modes when the system was more complex (three or four masses). To overcome this difficulty we tried to make the students to analyse an analogue and simpler system: a vibrating string with fixed ends. The first four normal modes are shown in the following picture.

![Figure 7. first normal modes of the string](image)

The students were now able to correctly associate oscillating masses positions with corresponding string vibrating points. The sketch draft by students is reproduced in Fig. 8.

![Figure 8.](image)

In addition, slow motion video analysis helped students in recognizing unexpected motion details, that is: displacement amplitudes and velocities are different for each mass.

**The coupled pendulums**

This system consists of two (three) physical pendulums coupled by one (two) springs. Each pendulum consists of a plastic disc stuck in the terminal part of a metal rod. Quantitative measurements are taken by using Vernier Logger Pro data acquisition system. The setup used for this experiment is the one shown in Fig. 2.

As a first step system oscillations are started according to its different normal modes and the corresponding frequencies are recorded; successively the system is started with a set of different initial conditions.

The data analysis software, by calculating the FFTs, provides the frequencies; these, although with different amplitudes, coincide with the expected normal modes frequencies.
This allows to show students that all the oscillations of the system appear to be a linear combination of the frequencies of normal modes.

The following plots show in sequence the two possible normal modes frequencies and their random superposition. On the right side of the single mode plots are shown the respective system configuration.

**Figure 9.** frequency of first normal mode

**Figure 10.** frequency of second normal mode

**Figure 11.** beats due to the superposition of the two modes and respective frequencies mixing

The students afforded the study of the two coupled pendulums experiment also via the Tracker video analysis. In this case it is possible to track simultaneously either pendulums and compare the waveforms due to the beats (see Fig. 12). They could realize that there is a complete energy transfer between the two pendulums. In fact, zero amplitude of oscillations for the first pendulum corresponds to maximum amplitude of oscillation for the second pendulum, as looked like at eye observation.

This video analysis software allows to track the center of mass motion. Here students can see that when the system is excited randomly each part of the system (each pendulum) describes a motion that is the linear combination of the two normal modes. This motion is not harmonic and in general neither periodic, while the motion of the center of mass results always harmonic (see fig. 13)
The experiment was implemented in the case of three coupled pendulums. We report, in the following figures, the results of the normal modes frequency detected and the effect of superposition of normal modes in the case of random excitation.

Figure 12. beats of two coupled pendulums

Figure 13. the center of mass harmonic motion

Figure 14. three coupled pendulums

Figure 15. the frequencies of the three normal modes
The Shive machine

A system of a fifty coupled torsional oscillators helps introducing a near to continuous system. The system has as many normal modes as the number of torsional pendulums (in number equal to system degrees of freedom). In the figure are shown the first two modes.

The vibrating string

A vibrating string, as shown in Fig. 7 is a continuous oscillators system with infinite degrees of freedom. The first modes are very similar to the Shive machine equivalent modes.

Chladni plates

A two dimensional system has been observed by students. They could see the many configurations of normal modes forming as exciting frequencies increase.

Neither quantitative nor qualitative analysis can be done, but a simple observation of characteristic standing forms appearing, as can be seen in the following pictures.


Figure 18. normal modes in two dimensions: different shape Chladni plates

6. Results

From the brainstorming/interview with students it emerged that about 80 per cent of students thought that if a mass attached vertically to a spring is displaced of a certain quantity, the greater the displacement, the greater the frequency of consequent oscillation. Some students stated: “the frequency is higher because with a wider displacement you have a faster movement of the mass”, this despite the fact that almost all students knew the pendulum isochronism law. After performing the experiment and the subsequent analysis of the waveform obtained either from a harmonic oscillator or from a simple pendulum with different displacements, most students agreed that frequency did not depend on amplitude of oscillation. The related question in the final test has been correctly answered by nearly ninety per cent of students.

Another important point that emerged from the interview concerned the description of the motion configurations of the mass-spring system. When students had to deal with a two masses and three spring system, most of them were able to correctly predict the motion configurations of normal modes. In case of three and four masses most students could predict the first normal mode but very few were able to predict the subsequent modes. None was able to describe the fourth mode (four masses). On the other hand finding out several normal modes in the case of the string (Fig. 7) was not difficult for most students.

After introducing the analogy-graphic method (see student sketch in Fig. 8) the number of students able to predict the motion configuration of higher normal modes increased significantly. In the final test a question on a system of four masses and 5 springs was proposed. All students were able to describe (verbally and/or by plots) the first normal mode; nearly sixty per cent correctly described the second; over fifty per cent described the third and over forty per cent the fourth. Most students giving a wrong answer on third and fourth normal modes just did not accurately draw the sketch in Fig. 8. Few students pretended to identify a fifth mode because they associated the number of degrees of freedom with the number of springs instead of the number of masses.

The use of slow motion video analysis resulted particularly useful for the understanding of motion details that the students were not able to grasp by the naked eye. For example most students did not recognize the increase of frequency with increasing normal modes.

Some other knots emerged from the experimentation: the difference between the oscillation of the system and the oscillation of each mass in a normal mode, and the conceptual difference in thinking of normal modes and of stationary waves in a string.

The final result is that the use of data logging techniques and the use of video and slow motion are worthwhile for reasoning on normal modes.

We would like to stress that this was just a preliminary (pilot) experimentation on normal modes. A wider experimentation with more quantitative evaluation of the sequence will be implemented in the near future.
7. Conclusion

The physics education research group of the University of Milano has been working for many years to the implementation of teaching/learning sequences in quantum physics. Within this path a major importance is given to normal modes of oscillating systems seen as building tokens for understanding waves phenomenology.

At this aim we have implemented a teaching and learning sequence on vibrating systems normal modes. The sequence was based on experimental approach and was experimented on two different groups of upper secondary school students.

Here we described the teaching/learning sequence and reported the most significant experiments we proposed to the students. We also reported the most significant results of this experimentation.

The overall results show that the experimental approach with the use of data logging system analysis and the video tracking/analysis, helps to improve the comprehension of normal modes phenomenology.

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Use of Graphics and Tables in Argumentation Written Task about an Energy Dilemma in Secondary School

Marina Castells, Universitat de Barcelona
Aikaterini Konstantinidou, Universitat de Barcelona
Sandra Gilabert, Universitat de Barcelona

Abstract

Argumentation has recently become a common topic of research in science education. However, few researchers have studied the influence of a given text’s characteristics on students’ performance of a task and on their argumentation, neither is common to find studies that deals with the use of tables and graphs as an evidence to justify a given argument. The present work analyzes the arguments of the texts built by students to justify a given claim in an argumentation written task about an energy dilemma. The task, performed individually by students from two secondary schools, had two parts. In the first part they had to decide about the dilemma and to justify their position in a written text on the base of the information given to them as a verbal text that included arguments. In the second part, the data (graphs or tables) were given to students and they had to write a second text confirming or changing their previous position with the support of the data. The study examines how the arguments given in the energy dilemma written text and the data presented through graphs and tables, influence students’ individual pieces of writing on this subject in both parts of the task. From the results of the study, we conclude that these students are able to elaborate texts with high quality argumentation in both parts of the task, although they didn’t receive any specific instruction about argumentation. The structure of the argumentative texts is very complex in many cases and presents important differences between different students.

Introduction

Argumentation has recently become a common topic of research in science education (Castells et al., 2007; Erduran & Jiménez-Aleixandre, 2008; Buty & Plantin, 2008). This research field includes the study of discursive practices that occur in the construction of science (and in science learning), the articulation and justification of scientific statements, and the arguments and counter-arguments that can be given in theoretical or practical scientific (Latour, 1987; Mayer, 2005) or scholarly contexts (Duschl, 1999; Jiménez-Aleixandre et al., 2000; Erduran et al., 2004; Simon et al., 2006; Castells et al., 2007). Studies on argumentation have involved students carrying out several types of tasks (writing a text, a group discussion, completing a questionnaire, a whole class discussion, among others). However, few researchers have investigated how the characteristics of a text given to students influence the performance of an argumentation task.

On the other hand, the interpretation and construction of graphs is a classic topic still present in science education research (Janvier, 1987; Wu & Krajcik, 2006). In contrast, research on learning to construct and interpret tables is very scarce (Martí, 2008). Still less common is to find research that deals with the use of tables and graphs as evidence to justify a given argument.

Research in science education has emphasized pedagogical strategies that foster arguments and discussions (Driver et al., 2000; Simon et al., 2006; Kelly, 1986; Khun, 2005). This is in line with research on Critical Thinking (Ennis, 1987), which considers argumentation an essential skill to develop (Ennis, 1992; Felton, 2004). In a broad sense, our work will also contribute to this field.

The aim of this study is to investigate how the argumentative characteristics of an energy dilemma text influence students’ individual written pieces. One important characteristics of the energy dilemma is that it has two parts. In the first part, students have a verbal written text which includes arguments and, in the second part, some graph/tables are given to students as evidences for their justifications.
Our framework is based on several studies on argumentation and the general concept of an argument consisting of a claim and one or several reasons that are used to defend the claim or conclusion which comes from several authors from Philosophy and Psychology fields of research (Van Eemeren, 2004; Walton, 1996, 2006; Perelman, 1958; Toulmin, 1953).

Methods

The sample consists on two groups of 13-14 year old students from two secondary schools in Barcelona. Each group was made of approximately fifty students.

A dilemma about two sources of energy was presented to students. The task performed by the students, individually, had two parts. In the first part, they had to decide about the dilemma and to justify in a written text on the base of the information given to them as a verbal text which includes arguments. In the second part, the data (graph/tables) were given to students and they had to write a second text confirming or changing their previous position with the support of these data. Students had to perform the task individually.

The dilemma given to students in the first part of the task is not a simple text. Its construction is based on how dilemmas used to be presented to students. It includes two possible options and two main arguments (we use the term “reasons” in the written text) in favor of each of the options (construction of a nuclear power station and construction of a fossil-fuel power station). Each one of these main argument includes several partial arguments (smaller reasons) that could be presented as positive reasons for supporting one of the options or as reasons for rejecting the second option. In summary, the text includes claims, justifications, limitations and contra-limitations in a structured complex way.

Students performed both parts of the task individually in one session of their regular mathematics class (50 minutes), in the presence of the teacher of mathematics and two researchers.

In the first part of the task, the dilemma was given to students on a sheet of paper and they had to write answering the first part of the task on another sheet. Consequently, they had a lot of space for writing and many of them produced very long texts.

In the second part of the task, four graph/tables were given to the students as data they can use to justify their previous option or to change it. Half of the students had tables and the other half graphs. We asked them to write a second text confirming or changing their previous position with the support of the data.

To build our analytical framework, we adapted theoretical concepts used in other researches and we identified the main elements of a single argument or of linked arguments. In particular, we identified claims, justifications, limitations, contra-limitations, and contra-claims. According to our adapted framework:

Claims are the option or thesis that is supported.

Justifications or reasons, which can be positive or negative, are the information given by the student to support their claims or reject the other option. They can include relevant information from the dilemma text or from the media, as well as ideas, opinions, values or personal experiences that support the chosen option.
Limitation is an argument or reason that considers and includes negative or missing aspects of the main argument that a student gives in favor of the chosen option. A limitation can also recognize positive or convincing aspects of the arguments given by other people in favor of the rejected option. In general, in an argumentative text, a justification can be about the claim, another justification, a limitation, etc.

Contra-limitation is used to resolve a limitation. These arguments reduce the negative weight of a limitation. In some cases, we can also find contra-claims, which we define as claims that differ from the chosen option and are in fact against this option.

Contra-claims are claims presented as an alternative to the claims in the dilemma or to the first claim defended by the student.

Examples of the above categories:

<table>
<thead>
<tr>
<th>Claim</th>
<th>I defend Project 2: installation of a nuclear power station proposed by the ENE company.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Justification of the fossil-fuel power station</td>
<td>Because this cannot affect people as nuclear energy would do. J1 In addition, I think it is better because there will not be any radioactive leaks. J2</td>
</tr>
<tr>
<td>Justification of the nuclear power station</td>
<td>The main reason, as explained in the texts, is that coal and the rest of the fossil fuels cannot be renewed in a short period of time, and so, after a certain time, the thermal PS would not be useful and it would have been a waste of money.</td>
</tr>
<tr>
<td>Limitation</td>
<td>Though it is true that a nuclear PS can be more dangerous and could involve risks of nuclear accidents....</td>
</tr>
<tr>
<td>Contra-limitation</td>
<td>But it is also true that risks have to be taken to gain rewards</td>
</tr>
<tr>
<td>Contra-claim</td>
<td>I wouldn’t vote for either of them because I don’t think they are good options. ..... I would have proposed the solution of putting solar panels on the roof of every house...</td>
</tr>
</tbody>
</table>

**The instruments**

An analysis of the text of the dilemma shows that there are two main justifications (reasons) that include partial arguments (justifications or reasons) about each of the two possible claims in the dilemma. The second reason or main argument in defense of the fossil-fuel power station claim is a limitation with a contra-limitation. The main reasons (or arguments) for defending the nuclear power station include several justifications or partial arguments. In fact, the dilemma given to students has a tree structure, as presented below (Figures 1 and 2). Our hypothesis is that we will also find tree structures in the students’ arguments, due to the influence of the dilemma’s structure. In our analysis, we will assess whether this hypothesis is true.

In addition, we consider that not only the arguments included in the written text can influence students’ written text but also the way the task is presented to students, which is a very rhetorical personal way. Below we illustrate these ways (Table 1 and 2).
**Figure 1.** Structure of the argument (reason) in favor of Project 1 (fossil-fuel power station)

General CLAIM: I prefer Project 1 (fossil-fuel power station)

1st reason (BECAUSE...) 2nd reason

**JUSTIFICATIONS (J) or REASON** for selecting Pr. 1

- J1 (in favour of P1 +)
  It solves the problem of obtaining energy

- J2 (against P2 -)
  There is no risk of nuclear accidents

**SUPPORT (because...)**

- J21
  Radioactive substances are not handled in fossil-fuel PS

- J22
  Many countries have replaced NPS

**CONTRA-LIMITATION (CL)**

- L1: Fossil-fuel power stations send CO₂ to the atmosphere
  (Even so, Despite of)

- JCL1
  Changes in temperature are cyclical.

**Figure 2.** Structure of the argument (reason) in favor of Project 2 (nuclear power station)

CLAIM: I prefer the Project 2 (nuclear power station)

1st reason (BECAUSE) 2nd reason

- J1
  No CO₂ emissions
  So this stops the greenhouse effect

- J2+ ..........
  There are very large uranium reserves

- J3
  Coal and oil are not renewable

**SUPPORT (because)**

- J11
  Damages P-S PS produce a third of total CO₂ emissions
Table 1. The way as the demand is presented to students in the first part of the task

Imagine that you are the Major of your town and that you will be the last person to vote. When this moment arrives, there is a tie between the two projects, so your vote will have a vital importance because it would be decisive. The responsibility is then in your hands and as Major you have to choose one of the two options proposed by the Catalan Government to solve the energy problem of Barcelona. Before to chose, value adequately which of the two projects is more appropriated and think deeply the arguments by which you chose one of these two projects:

Project-1: Installation of a thermical power station by combustion of fossil fuels (coal and Petrol) proposed by the company C.O.F.

Project-2: Installation of a nuclear power station proposed by the company E.N.E.

Explain in this sheet the reasons that justify the election of your project. IT IS VERY IMPORTANT THAT YOU JUSTIFY THE IDEAS YOU USE TO DEFEND YOUR POSITION.

Table 2. The way the demand to students is presented in the second part of the task

Here there are some data procured by the University of Barcelona. Do they give support to your previous position?

- In the case they give support to it, justify once more your vote. It is very important that now USING THE MATERIAL WE GIVE TO YOU, explain again in the paper the reasons that give support to your vote.

- In the case that you had changed your opinion, justify your new vote. It is very important that USING THE MATERIAL WE GIVE TO YOU, you explain in the paper the reasons that give support to your new vote.

ABOVE ALL, as in the first task, you HAVE TO JUSTIFY THE IDEAS YOU USE TO DEFEND YOUR POSITION.

In this second text of the demand, it is very clear that we ask to the students their justifications using the material (the data which are graphs or tables).

Data analysis and findings

1. Categories for the analysis

In the analysis of the students’ texts given in the first part of the task, they were coded according to: 1) the types of claims (nuclear project, fossil fuel project, another type of energy source, it is not possible to choose); 2) the number of reasons or arguments; 3) the types of arguments according to the content of students’ texts and comparisons with the arguments given in the dilemma text; 5) a qualitative analysis of the elements and structure of the argumentative texts of students that will give some appreciation of the argumentative skills and of critical thinking of the students.

Related to the analysis done for the second part of the task, the students’ texts were coded according to: 1) keeping or changing their position, related to the first task; 2) using the tables or graphs to defend their positions and/or to disconfirm the alternative position; 3) giving the same arguments or adding new arguments in the second text in comparison with the first text; 4) the specific strategies used to integrate the tables or graphs into their arguments; 5) a qualitative comparison between the elements and structure of the argumentative texts of the students in this second part of the task.
2. Some results about the first part of the task

The claims

Table 1. Summary of claims made by students (first breakdown)

<table>
<thead>
<tr>
<th>School</th>
<th>Fossil-fuel PS (including forced choice)</th>
<th>Nuclear PS (including forced choice)</th>
<th>Other option</th>
<th>Not possible to choose</th>
<th>No answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>School 1</td>
<td>36</td>
<td>46</td>
<td>8</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>(50)</td>
<td>(18)</td>
<td>(23)</td>
<td>(4)</td>
<td>(4)</td>
<td>(1)</td>
</tr>
<tr>
<td>School 2</td>
<td>39.7</td>
<td>55.2</td>
<td>3.4</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>(58)</td>
<td>(23)</td>
<td>(32)</td>
<td>(2)</td>
<td>(1)</td>
<td>(0)</td>
</tr>
<tr>
<td>Total</td>
<td>38</td>
<td>50.9</td>
<td>5.6</td>
<td>4.6</td>
<td>0.9</td>
</tr>
<tr>
<td>(108)</td>
<td>(41)</td>
<td>(55)</td>
<td>(6)</td>
<td>(5)</td>
<td>(1)</td>
</tr>
</tbody>
</table>

In the first part of the task, approximately half of the students (51%) chose the nuclear power station and fewer students (38%) chose the fossil-fuel power station. Many students stated that they would prefer another renewable type of station. However, as we asked them to choose between two options, they did this even though they did not like either of them very much. Quite a considerable percentage of students chose an alternative source of energy or said that it was not possible to choose (10%).

If we want to highlight the students who did not like the options given in the dilemma, we can break down the categories in another way, by combining ‘Other option’, ‘Fossil-fuel power station, forced choice’ and ‘Nuclear power station, forced choice’, as these three mean ‘students who did not like the claims in the dilemma’. In this case, we find that nearly 20% of students did not like the two options given in the dilemma. Despite this percentage, near half of the students (46.3%) chose the nuclear power station, i.e. more students chose the nuclear power station than the fossil-fuel power station.

The arguments

We consider that the concept of argument consists of a thesis or claim and reasons given to defend or reject this thesis (claim). Each reason can be independent, have other reasons supporting it or some limitations.

Number of arguments

Students gave one or more reasons in their written texts. We count these reasons as arguments. More than 40% of the total sample gave more than three arguments or reasons to justify their chosen claim, and nearly 40% gave three arguments. Our hypothesis is that there are many partial arguments (reasons) in the dilemma, which students are able to use in their texts or take as inspiration to construct their own arguments. In fact, it seems that the information they read in the dilemma helped provide them with reasons to use.

It is interesting to note that when students did not agree with either of the options given in the dilemma, they gave more than three arguments, this is a result.

b) Types of arguments (reasons) by content

Most students’ used mainly the reasons given in the dilemma in their arguments. However, some students introduced new reasons that were not included in the dilemma. We categorized the students’ arguments into seven types according to its content. These categories are presented below.
<table>
<thead>
<tr>
<th>Type of partial argument or reason</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents</td>
<td>Students mention accidents, or talk about hazards in general without specifying much about these risks.</td>
</tr>
<tr>
<td>Radiation leaks/hazards of radioactive substances</td>
<td>Students refer specifically to radiation leaks or risks due to the treatment of radioactive substances.</td>
</tr>
<tr>
<td>CO₂ and climate change</td>
<td>Students relate CO₂ emissions with climate change</td>
</tr>
<tr>
<td>Cyclic CO₂</td>
<td>Students refer in a positive or negative way to the idea that CO₂ emission is a cyclic process that does not cause climate change.</td>
</tr>
<tr>
<td>Fossil resources</td>
<td>Students talk of fossil resources (coal, crude oil) that are not renewable.</td>
</tr>
<tr>
<td>More uranium</td>
<td>The uranium used in the nuclear power station is abundant in nature or more abundant than fossil fuels</td>
</tr>
<tr>
<td>Contamination</td>
<td>They talk of contamination that sometimes means CO₂ and some other substances from the power station or radioactive substances leaking from the power station.</td>
</tr>
<tr>
<td>No need for more sources of energy.</td>
<td>They consider that there are enough power stations and so there is no need to build new ones.</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Students state that nuclear stations or fossil-fuel stations are more efficient.</td>
</tr>
<tr>
<td>Nuclear waste problem</td>
<td>They present the problem of nuclear waste, generally considering it to be negative.</td>
</tr>
<tr>
<td>More safety in nuclear stations (new technologies, more modern technologies, etc.)</td>
<td>Students accept nuclear power stations because the technology will continue to advance and this will help prevent accidents or leaks.</td>
</tr>
</tbody>
</table>

On the basis of these categories, we compiled a table of the types of partial arguments or reasons given by students in the first part of the task (% of the number total of reasons in each group), but we do not include here, because of the length of the paper. From this table we can say that, in general, students mainly argued using the reasons given in the energy dilemma text, but which is interesting is that some introduced new reasons of their own. The most common argument or reason given by students was ‘CO₂ is considered a cause of climate change’, followed by ‘other types of reasons not given in the dilemma’. Students presented arguments or reasons of their own, such as ‘we live in a sunny country where solar panels can be used’ and ‘the problem of nuclear waste’. We believe that some reasons were taken from media sources, particularly because some months before the students carried out the task, there had been a very strong debate in Catalonia about where to build a store for nuclear waste. The argument or reason of ‘the hazard of nuclear accidents’ was given by a high percentage of students, as was the ‘fossil resource’ argument. These comprised nearly 12% of the total reasons given by the students.

It is also interesting is to analyze the types of arguments in relation to the claim chosen by the students. We compiled a table by combining ‘Fossil-fuel power station with fossil-fuel power station, forced choice’ and ‘Nuclear power station with nuclear power station, forced choice’. One result is that the types of reasons seem dependent on the chosen claim. When students chose the claim ‘Fossil-fuel power station or forced choice’, the highest percentage of reasons corresponded to ‘nuclear accidents’ (21.1%), followed
by ‘radioactive leaks’ (12.8%) and ‘other reasons not in the dilemma’ (12.8%). When students chose the claim ‘Nuclear power station’ or ‘Nuclear station, forced choice’, the highest percentage of reasons corresponded to ‘CO₂ climate change’ (23.4%) and ‘there is more uranium’ (15%).

c) Types of justifications in comparison with the justifications in the dilemma

We defined the following categories for the analysis:

<table>
<thead>
<tr>
<th>Types of justifications in comparison with the justifications in the dilemma</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Like the justifications in the dilemma</td>
<td>This category includes students who gave the same reasons as in the dilemma. The students’ reasons are only part of the main reasons in the dilemma.</td>
</tr>
<tr>
<td>H. Like the justifications in the dilemma, but adapts or mixes parts from more than one justification</td>
<td>This includes ideas that are in the reasons of the dilemma, but the students only use them partially and change the form of expression and/or combine one part of a reason with parts of other reasons.</td>
</tr>
<tr>
<td>I. Like a justification in the dilemma, but with an added opinion or evaluation</td>
<td>This category was created as some students add an evaluation or opinion to the reasons given in the dilemma.</td>
</tr>
<tr>
<td>J. Justification included in the dilemma, but it was reinterpreted or its meaning changed</td>
<td>Student gathered the information given in a justification/reason for the dilemma, but he/she misinterpreted it and used this information with a different meaning.</td>
</tr>
<tr>
<td>K. New justification that is not included in the dilemma and is not a personal opinion</td>
<td>This category includes new justifications that were not included in the dilemma.</td>
</tr>
<tr>
<td>L. New justification that is a personal opinion and not based on relevant information</td>
<td>This category includes new justifications with opinions or personal evaluations that do not refer to something relevant from the perspective of a science or social problem.</td>
</tr>
<tr>
<td>M. New justification that is a personal opinion based on relevant information</td>
<td>New justification with a personal opinion, but with reference to some relevant information that is not necessarily certain or validated data; it only has to be meaningful to the students.</td>
</tr>
</tbody>
</table>

The general result of the study of the students’ written texts focusing on the above categories is that many students used the arguments given in the dilemma in their own way, by changing the order, mixing reasons for Project 1 with those for Project 2, cutting the arguments and using some parts only, and adding evaluations or reinterpreting them with different or opposite meanings. There are some differences between schools: students from School 1 gave more justifications like those found in the dilemma than students in School 2.

3. Some results about the second part of the task

a) Keeping or changing their position, related to the first task;

We found interesting that the majority of students maintain the same claim, using the tables and graphs as a support. Only 12.8% (16) of students from the total sample change position in the second task. Other result is that there is no significant difference in the percentage of students that change the claim between the ones that have tables as data or the ones that have graphs. Only 16.4% (10) of students that have tables change position and even less percentage, only 9.4% (6), of students that have graphs change position in the second part of the task.
b) Using Graphs/ tables to defend their positions and/or to disconfirm the alternative position.

The majority of students (73%) use the data (graphs/tables) given in the second part of the task. There is not significance difference between the percentages we find between the group of students that has tables (52%) or has graphs (48%) in the second task. The same with the percentages of students that do not use the given data (15%, tables, versus 13%, graphs).

c) The specific strategies used to interpret the tables or graphs in order to integrate them in their arguments.

We find several specific strategies coming from the way students interpret tables or graphs to its integration in the arguments, that go from a) literal reference to graphs or tables, b) reference to local data in the tables or data, c) reference to global trend in the tables or graphs, c) no reference to tables or graphs, d) interpreting adding a valuation of the data. These are not exclusive categories, so it is difficult to give clear results. Our initial hypothesis was that students which had graphs would have the reference to graphs mainly as global trend or local + global trend and that the students which have tables will use more local tendency, but the results say us we have to refuse our hypothesis. In fact, more students that have tables have reference to them as global tendency than students that do this having graphs. This is a provisional result because the differences don’t have statistically significance. Also we have to consider that the results have been taken from a sub-sample of our total sample.

We will not present here results about other aspects related to the arguments given by students in this second part of the task as: types of arguments in the second task according its content; keeping, discarding or adding arguments to the arguments given in the first part of the task; the specific strategies used to integrate the data (tables or graphs) into their arguments. Because the space we can use in this paper, we will only comment in the following part of the paper about the argumentative structures of students texts through a comparison between the ones identified in the first part of the task and the ones of the second part.

4. Qualitative analysis of the argumentative structure of students’ texts (first part of the task versus second part of the task)

According to our analytical framework, we identified claims, justifications, limitations, contra-limitations and contra-claims in the students’ written texts, where it is possible, and we constructed the tree structure of these elements.

We can find several argument structures that involve several levels:

![Argument Structures Diagram]

Theses combinations can become more complex, without or with repetition of the elements considered. Below, we present some of the answers and the complex structures that we identified in the students’ texts in the first part of the task and in the second part, to compare these structures in a qualitative way.

We name the students with a number followed by a T or by a G, according if we have give to him/her the tables or the graphs as data.
“I think that there is enough energy and power stations of different types of energy, such as wind, hydraulic and electrical energy, in Spain. Therefore, there is no need to build a new power station in Barcelona, and especially not in the middle of the city. In principle, I wouldn’t support either of the options because the two contaminate and damage the environment. But if I were forced to choose, I would prefer the fossil-fuel power station.

Arguments:

1st. I would choose this (fossil-fuel) because I think that crude oil and coal are materials that do not have any other uses except energy production (or the manufacture of some products). Therefore, it would not hurt anyone if these resources were used up. If this occurred, they would find a way to replace these materials in the future.

2nd. I have always been against nuclear power stations because I think that if a fault arises, a lot of damage can be caused and everyone will be hurt.

Condition: If one of these power stations had to be built, I would ask the Catalan Government to build it as far as possible from people to prevent catastrophes.”
**104 T 2n part**

“If I focus on the attached tables, I find still my idea more positive, because, the number of nuclear accidents is very high and the concentration of CO2 in the atmosphere has been always more or less the same, and there is not a big increasing in it despite the thermical power central were used.

Coming from these data, the true of the second reason from the COF which explain that the CO2 emissions don’t depend on and don’t have any relationship with these power stations is evidenced.

Despite of this, not all is positive, because I find confirmed that the world reserves of petrol are low, but we consider that coal is also possible to be used.

But, for the nuclear power stations the uranium is necessary to be used and this is very dangerous.”

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**19G 1st part**

‘Neither of the Projects because I do not think either of them is good; the fossil-fuel power station produces CO₂ and consumes fossil fuel resources which are limited, and the nuclear power station would produce too much radioactive waste, which lasts for a long time. I would propose the solution of putting solar panels on the roof of every house. Silica is present in soil, so it is very abundant in nature and solar panels would not emit CO₂ or radioactive waste. In addition, there is a lot of space for solar panels in Barcelona, this would not be a problem as all the buildings in Barcelona have roofs where solar panels could be placed. Barcelona is a very sunny town.”
"I confirm the same, neither of the two projects. On one side, it is seen that as we are wasting, we will be soon without petrol as the graph 2 says. On the other side, the accidents in the nuclear power stations, grave or not, occur in a big number (graph 1). Yes, it is true that the CO2 always has changed its volume in the atmosphere, even more than now (graph 3), but all this, added to the degradation we cause to the planet, can produce a big disaster. And more, we waste every time more without thinking about the bad consequences (Graph 4)."
“I maintain the same option (project 1).

From the table 1 I can defend that there is too much risk of nuclear accidents as I had said in the task 1. From the table 2 we can see that step by step the fuel is finishing, but I think as before that the security is the most important.

As the years passed we will be able to find alternative but now is the best we can do. In the table 3 it is said about the contamination of CO2 because it is a very worrying thing. I’m confident that alternative solutions will be found in order to stop this contamination.

And in the table 4 we can see that this contamination has increased in the last days. So, we have to find solutions as soon as possible.”
“I agree with the Project 1 (in the case the climate change was not caused by the CO2), although it is an alternative that doesn’t like to me because the fossil fuels are finishing. The construction of hydraulic, wind, solar, etc... power stations would have to be done in very big quantities.”
“Project 1. According to the graphs, is the climate change a history? Or not? In this case, I think that the use of fossil fuel is better, although I think that the electrical power stations are more necessary.”

Figure 3. Argumentative structures in the first part of the task versus the second part of the task.
These few examples show the argument structure of the students' texts in both parts of the task. We can conclude from these structures:

1) The argumentative structure of the energy dilemma text, given to students in the first part of the task, influences on the structure of the argumentative structure of the students’ texts. A quantitative study of the argumentative quality of the students’ texts is still underway, but from the qualitative analysis we have carried out, we can state that many students showed high quality argumentation, as they constructed highly complex argumentative texts that included justifications at several levels, two types of limitations (recognizing the limitations of a self-claim or the advantages of another refuted claim), contra-limitations, and, in some cases, a contra-claim, as in the example 19G. The most interesting aspect for us is that students had not received specific instruction about argumentation prior to the task. In this particular case, we consider that the structure of the dilemma text is a model that students try to imitate. But also, the knowledge of the context helped students to construct their arguments.

2) In some texts of the students, we see the influence of the data we have given to them, it is specially seen in the texts of students that have tables as data, more than in the case of having graphs as data, as we can see in the structure of the student 10T, or the one of 104T student which justifications are one to one linked to the specific tables given to them. In fact, our appreciation from the analysis of many of these structures is that the structures of the second part are a little more descriptive than the ones of the first part, as if students read the tables or the graphs one after the other and this condition their structures.

**Discussion and conclusions**

Our results do not agree with the results of other researches that state that the argumentative skills of students are of low level. However, most students did not demonstrate critical thinking. We found that many students accepted the information we gave them in the dilemma without criticism. We can also state that some students were influenced by the media. Therefore, a higher percentage of students accepted the construction of a nuclear power station, when the Catalan media had defended this type of power station at the time that the task was undertaken. Students do not use premises of scientific knowledge in their arguments.

Another conclusion of this study is the need to improve scientific learning. The identification of premises and argumentative structures in the students’ texts helps us to understand the way students think by themselves and to see the influence of their reading. It provides argumentative resources for the teacher to be used to help students to improve their scientific knowledge and their attitudes towards socioscientific problems at the same time.

We found interesting that the majority of students doesn’t change their claim when they have the tables and graphs as a support. To have tables or graphs as data is a factor that does not influence the students’ change of option.

The results of our study show us that the strategies used by the students in their interpretation of tables or graphics are quite different. This difference influenced the way the students construct their arguments. The integration of tables in their arguments is not easy for them because their interpretation is also more difficult and complex. An implication of our study could be that teaching tables in school should be more explicit and detailed than communly is done. We should pay more attention to the instruction of tables in school.

**Acknowledgements**

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**AFFILIATION AND ADDRESS**

Marina Castells and Aikaterini Konstaninidou
Department of Science and Mathematics Education, University of Barcelona
P. O. Passeig de la Vall d’Hebron, 171, (08014) Barcelona, Catalonia (Spain)

Sandra Gilabert
Department of Psychology of Education, University of Barcelona
Email: marina.castells@ub.edu
A Model of Conceptual Distribution for Physics Education

Alexsandro Pereira de Pereira, Programme of Physics Teaching, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

Fernanda Ostermann, Department of Physics, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

Abstract

In this paper, we outline a particular approach to conceptual change, based on the notion of “conceptual distribution”. This theoretical proposal is an attempt to reconsider the problem of conceptual change from a sociocultural perspective. Our basic assumption is the claim that conceptions are best understood as a form of mediated action. This approach is based on James Wertsch’s sociocultural analysis and it is grounded in an analogy between science conceptions and Wertsch’s account of collective remembering. According to this theoretical model, both scientific conceptions and misconceptions are “distributed” between active agents and the textual resources they employ, especially textual resources in the form of explanation (written or spoken). From this perspective, conceptions are viewed as being distributed: (1) socially, in small group interactions; and (2) instrumentally in the sense that it involves both people and instruments of knowledge. In the case of social distribution, most researchers recognize it when they examine the “collaborative” meaning making that occurs in science classroom when students work together to represent some aspect of physical reality. “Instrumental distribution,” by the other hand, involves agents, acting individually or collectively, and the cultural tools they employ, tools such as graphs, computer simulations, or explanations. Implications of this model for physics education are outlined.

Introduction

Since the 1970s, research in physics education was concerned with students’ prior ideas about physical phenomena. Many studies have shown that these conceptions are deeply rooted and often resistant to change. Since then, many efforts have focused on changing these ideas in ways that can lead students to a correct understanding of science concepts (Limón & Mason, 2002). The best known theory of conceptual change was developed in the 1980s by Posner et al. (1982). By taking philosophy of science as their major source of hypothesis, they outlined a particular model to explain “the process by which people’s central, organizing concepts change from one set of concepts to another set, incompatible with the first.” (p. 211). This classical approach to conceptual change, as it has been called in the literature, became the leading paradigm that guided research and instructional practices in science education for many years (Vosniadou, 2007b).

In the 1990s, however, the theory of conceptual change became the focus of strong criticism. According to Vosniadou (2007b), on the bases of this classical approach the child is like a scientist, the process of science learning is a rational process of theory replacement, conceptual change is like a gestalt shift that happens over a short period of time, and cognitive conflict is a major instructional strategy for producing conceptual change. Over the last two decades, all of these tenets have been seriously questioned. Linder (1993), for instance, has argued that conceptual dispersion is a phenomenon in both social lives and in science and that conceptual change depiction of learning should be extended to include conceptual fitting based upon context. Pintrich et al. (1993), by the other hand, referred to Posner et al.’s theory as a cold model of conceptual change because it focuses only on student cognition without considering the ways in which students’ motivational beliefs about themselves as learner can facilitate or hinder the process of conceptual change. These and other criticisms have led to what is called the “reframed approach” to conceptual change (Vosniadou, 2007b).
As Mason (2007) has pointed out, traditional research on conceptual change has been characterized mainly by a cognitive approach that focuses on analyzing personal mental representations. More recently, however, the debate between cognitive and sociocultural approaches that has dominated recent theorizing about learning and instruction has also been transferred into the field of conceptual change (Vosniadou, 2007a). In fact, the term “conceptual change” and other related notions such as “conceptual practice” (Krøncke, 2007) or “discourse change” (Wickman & Östman, 2002) have become a topic of renewed interest in sociocultural studies. One particular issue of this debate, also called “the cognitive-situative divide” (Vosniadou, 2007a), is whether conceptual change theory and sociocultural theories might be complementary or alternatives (Alexander, 2007; Mercer, 2007; Roth, 2008; Treagust & Duit, 2008). Many authors are now reconsidering the problem of conceptual change from a sociocultural perspective (Furberg & Arnseth, 2009; Greeno & Sande, 2007; Roth et al., 2008).

**Method**

One influential features of conceptual change research is the analogy with the history and philosophy of science (diSessa, 2006). Sometimes, this analogy is made at the level of the content, connecting students’ prior conceptions with medieval scientific theories (e.g. McCloskey, 1983). In other times, this is made at the level of the mechanism of change, connecting Piagetian processes of “assimilation” and “accommodation” in the individual with Kuhnian periods of “normal science” and “scientific revolution”, respectively (e.g. Posner et al., 1982). In its most uncompromising form this line of reasoning adheres to the “recapitulation theory” (Caravita & Halldén, 1994). From this viewpoint there is a direct parallel between concept formation in the individual learner and concept development throughout the history of science.

According to Wertsch (1991), most recapitulationist notions are now largely rejected in psychology although their implicit presence is often apparent in the methods used to collect and analyze empirical data. This seems to be exactly the case for research on conceptual change. In a preface of the volume Reframing the conceptual change approach in learning and instruction, Vosniadou et al. (2007) wrote that they were “interested in examining some of the criticisms of Kuhn’s theory and in understanding how they apply to conceptual change research in learning and instruction.” (p. xxi). In a review of the history of conceptual change research, diSessa (2006) used Toulmin’s arguments to attack what he called “the theory theory” approach to naïve physics. As Pozo (1999) has noted, in theorizing about learning it is not uncommon to see some “argumentative jumps” between distinct levels of analysis (e.g. sociocultural history, ontogenesis and microgenesis). In fact, there is no reason to assume that what happens in one level can be easily transferred to another. According to Wertsch (1991), in Vygotskian tradition each “genetic domain” is governed by a unique set of principles, which precludes any form of recapitulationism.

In view of the above-mentioned, we advocate a “change of analogies”. Instead of making an analogy with history of science, which corresponds to a distinct level of development, we propose an analogy between science conceptions and collective memory. According to Wertsch (2008), collective memory is a representation of the past shared by members of a group such as a generation or a nation-state. Instead of focusing on individual experience and memory, the study of collective memory examines social phenomena such as commemoration, history education, and mass media to understand how they give rise to shared accounts of the past. We believe that this analogy with collective memory can provide new insights to the problem of conceptual change. Moreover, by being based on Wertsch’s approach to sociocultural analysis (Wertsch, 1998, 2002), grounded mainly in Vygotskian tradition, our proposal incorporates many features of the “genetic method” (Wertsch, 1991), avoiding the pitfalls of the recapitutionalism that have obscured conceptual change research in physics education for many years.
Data and findings

The conceptual distribution model is a theoretical proposal to analyze the dynamics of conceptions in the science classroom. This is a sociocultural model of conceptual change, based on the notion of “conceptual distribution”. Drawing on Wertsch’s (1998) ideas about mediated action, we outline a particular version of conceptual change that focuses on how cultural tools, especially explanations, mediate its functioning. This approach is grounded in an analogy between science conceptions and Wertsch’s (2002) account of collective remembering as it is shown in the table 1.

Table 1. Collective remembering and conceptual distribution.

<table>
<thead>
<tr>
<th>Wertsch’s account of collective remembering</th>
<th>A sociocultural model of conceptual distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>It focuses on collective memory</td>
<td>It focuses on science conceptions</td>
</tr>
<tr>
<td>It is about historical events (the past)</td>
<td>It is about natural phenomena (the reality)</td>
</tr>
<tr>
<td>It is based on national narratives</td>
<td>It is based on scientific explanations</td>
</tr>
</tbody>
</table>

Our basic assumption is the claim that science conceptions are best understood as a form of mediated action. In other words, conception is a matter of people using cultural tools that are provided by a particular sociocultural setting. And because these tools are provided by these sociocultural settings, science conceptions are inherently “situated” in a social and cultural context. In the terminology of contemporary cognitive science, science conceptions are “distributed” between active agents and the textual resources they employ, especially textual resources in the form of explanation (written or spoken). From this perspective, these textual resources always have a history of being used by others, and as a result bring their own voices to the table. In view of the above mentioned, the task of sociocultural analysis becomes one of listening for the texts and the voices behind them as well as the voices of the particular individuals using these texts in particular settings (Wertsch, 2002).

According to our model of conceptual distribution, science conceptions are viewed as being distributed: (1) socially, in small group interaction, and; (2) instrumentally in the sense that they involve both people and instruments of knowledge. In the case of social distribution, most researchers recognize it when they examine the “collaborative” meaning making that occurs in science classroom when students work together to represent some aspect of physical reality. “Instrumental distribution,” by the other hand, involves agents, acting individually or collectively, and the cultural tools they employ, tools such as graphs, computer simulations, or explanations. In the case of textual resources, it does not mean that such explanations mechanistically determine how we think and speak about the physical world, but it is to say that their influence is powerful and needs to be recognized and examined. What all this suggests is the need to make visible and to understand the role of textual mediation in science conception. Our use of the term “text” derives from the writings of Bakhtin (1986) which defines it as a basic organizing unit that structures meaning, communication, and thought.

It is important to notice that according to this model of conceptual distribution, there is no sense to say that people “have” conceptions independently of any context given by mediated action. As Marton (1981) has argued, a “conception exists in the real world only in terms of a mental act and it is exhibited by someone who does something in a certain setting.” (p. 196). This approach contrast with perspectives based on the “acquisition metaphor” (Sfard, 1998), which defines knowledge as something that can be acquired and changed. From the perspective of conceptual distribution, it is not our conceptions that define the way we explain the physical world, as assumed by studies of mental models (e.g. Vosniadou, 1994). Instead, it is the explanation we learn to use that shapes our conceptions (i.e., the way we think and speak about the physical reality). This is consistent with the claim that “it is not experience that organizes expression, but the other way around – expression organizes experience. Expression is what first gives experience its form and specificity of direction.” (Volochinov, 1973, p. 85).
Discussion and Conclusions

The model of conceptual distribution has several implications for physics education. One particular implication is that it suggests a redefinition of “learning.” From this perspective, learning science is a matter of mastering scientific explanations provided by others. Among other things, this implies that explanations students provide in the classroom are not the product of independent research. Instead, they constitute an item from an “explanatory store” (Kitcher, 1989) which is an essential part of the “tool kit” (Wertsch, 1991) that exists in their sociocultural settings. This is not to say that students simply repeat these explanations mindlessly. When challenged they are quite capable of backing up their own explanations with additional information. This means that textual resources used in physics education usually do not take the form of isolated units that are either used in unmodified form or not used at all. Instead, they constitute a much more flexible kind of instrument that can be harnessed in combination with others in novel ways (Wertsch, 2002).

Moreover, by using the “tool metaphor” it becomes clear that the mastery of a new explanation does not imply the disappearance of daily forms of talk – which most researchers tend to label as “misconceptions”. As different explanations generate different representations of physical reality, it is possible for the individual coordinate alternative points of view. In fact, it is well known today that it is possible to use different ways of thinking in different domains and that a new conception does not necessarily replace previous and alternative ideas (Mortimer, 1995). That is exactly what Linder (1993) meant when he wrote that “conceptual dispersion is a phenomenon in both social lives and in science” (p. 293). That is, even a physicist with a strong training in quantum mechanics think about light in terms of electromagnetic waves in one context and in terms of photons in another. It calls on us to understand why some forms of explanation, as opposed to others, are “privileged” (Wertsch, 1991) in particular contexts.

Another implication of this conceptual distribution model for physics education concerns the role of social process in the formation of science conceptions. In fact, by considering explanations as cultural tools, the focus changes from cognitive to social plane. This is so because the category of “cultural tools” is the key to understand how a conception can be distributed across members of a group. From this perspective, members of a group share a representation of physical reality because they share textual resources. And because different settings presuppose different cultural tools, different groups can have quite different account of physical reality (i.e., different conceptions). Thus, one may view physics education in terms of border crossing into the subculture of a different group (Aikenhead 1996).

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References


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The Effectiveness of Laboratory Work in Physics
A Case Study at Upper Secondary School in Sweden

Jan Andersson, Department of Physics and Electrical Engineering, Karlstad University
Margareta Enghag, Department of Mathematics and Science Education, Stockholm University

Abstract

The present paper reports on a case study that examined the effectiveness of a practical activity in
physics, at a Swedish upper secondary school. A teacher and 19 students participated in the study.
The students were observed while working with the topic motion, in a computer based laboratory
environment (CBL). This case study is part of an ongoing longitudinal study, about the role of laboratory
work with different degrees of freedom. The analysis of interviews, written reports and posttest, shows
that the practical work was effective based on Millar’s model. Even so, the students had difficulties
expressing what they learned from the activity. This study emphasizes the complexity of planning and
conducting laboratory work that is effective, from several different aspects.

Keywords: Physics education, Laboratory work, Effectiveness, Experiences, Computer based lab

1. Introduction

This study will explore the students’ views and experiences of a physics laboratory activity, and aim to
contribute to develop the meaning of effectiveness of laboratory work as inquiry based learning, prescribed
in the new Swedish curricula for physics in upper secondary school.

Much of the scientific knowledge we now possess, originate in observations and experiments. Therefore,
teachers and researchers in particular find it natural that teaching in science subjects should include laboratory
work. Angell (2004) argues that physics is both a theoretical and experimental subject, which also must be
reflected in teaching. This view of physics education can be traced back to the early 1900s. However, educational
research from the early 70's indicated that the importance of laboratory work for student learning was minor
or insignificant. This started a discussion about the role of laboratory work and closed labs as working form
(Flansburg, 1972). Roth, McGinn, and Bowen (1996) argue that the closed labs results in that science knowledge
is neglected and that focus is only on using equipment. Abrahams and Millar (2008) observed 25 practical
lessons in different scientific disciplines. Teachers were interviewed before and after class. Observations of the
practical work carried out proved to be effective in the sense that the majority of students did what they have
been asked by the teacher to do. The teachers were most focused on getting students to understand how they
would perform the task. The lesson was from the teachers perspective successful if the students had managed
to recreate a phenomenon and made the comments which they were supposed to.

According to Abrahams et al. (2008) the efficiency of the practical work can be improved. Teachers and
authors of educational materials need to realize that practical work requires that students make connections
between the real world, materials, events and the abstract world, thoughts and ideas. Abrahams et al.
(2008) argues that science is about the interplay between ideas and observations. Practical work plays
an important role in helping the student establish a link between observations and ideas. But these ideas
must be introduced to the students and the interaction has to exist there during the activity. The study
shows that few practical lessons are designed to stimulate this interaction. The teacher must strive to find
a better balance between “doing” and “learning” in practice. Séré et al. (1998) found in the LSE project the
same thing, stressing the importance of further research in this area.

In a Swedish context, the physics teachers are responsible for implementing new ideas for physics teaching
and learning. The new syllabus Gy 2011 (Skolverket, 2012) gives guidelines for central content areas and for
important aspects that have to be included into the courses, but do not prescribe how to teach this content.

“The course will include scientific working methods to formulate and answer questions, plan and carry out
observations and experiments, and manipulate, interpret and critically evaluate results and information.
Students should be able to analyze and solve problems through reasoning based on concepts and models,
both with and without mathematics. In education, students are given opportunities to argue about and present analysis and conclusions. They should also be able to use computer-aided equipment for the collection, simulation, calculation, processing and presentation of data” (Skolverket, 2011)

The new Swedish physics curricula makes the laboratory work content and its importance for learning of high research interest, as it put an increased focus on students’ active participation in the whole inquiry process, from formulating a question to carry out a full inquiry to find an answer. In traditional physics teaching, the laboratory work is mostly used to make connections between theory and practice, and many activities concern core concepts, very close to a physics phenomenon. The new Swedish physics curricula prescribes that the students are given opportunities to be more involved in the sense that they can argue, analyse and conclude from their own inquires.

The meaning of effectiveness of laboratory work will by this go beyond the view found in literature, that laboratory activities’ effectiveness can be analyzed from two aspects: 1) what the students’ should do in relation to what they actually do. 2) Student’s learning outcome in relation to the teacher’s intention (Tiberghien, Veillard, Le Marechal, Buty, & Millar, 2001). A first step, however, will be to analyse a laboratory task for effectiveness as found in the literature, and then suggest improvement in the methods of analysis of effectiveness that include a view of a more empowered student.

This case study takes departure from a teacher’s introduction of a practical work within the new curricula. The students will discuss position, velocity and acceleration, when walking in front of a motion detector. The teacher has several intended learning outcomes of this activity, and we will analyze the effectiveness of the laboratory work related to the students learning outcomes expressed in interviews and written reports, but also the links between what the students actually do during the activities and how this is related to the teacher’s intentions.

1.1 Theoretical framework

1.1.1 Literature on laboratory work

Laboratory work is considered to be a central element in science teaching (Hogstrom, Ottander & Benckert, 2006). Studies have shown that laboratory work in practice often focuses on the actual implementation, rather than on what students can learn from the lab (Hodson, 1990; 1991; Hofstein & Lunetta, 2004; Millar et al., 2002). Hogstrom et al. (2006) have shown that according to Swedish teachers, there are important goals to achieve with the help of laboratory work. The practical work gives the students opportunities to learn science, getting them interested and accustomed to laboratory work. In order for students to understand what is important to learn, however, teachers need to clarify this in speech and action (Hogstrom, Ottander & Benckert, 2009). The authors also believes that it is important that the teacher is aware of the goals he/she has with the specific lab and make this clear to the students to then act against these targets. Students who rarely or never understand the purpose of what is done in the classroom will not likely perceive science as a meaningful activity (Wickman, 2006).

1.1.2 Efficiency of laboratory work

The Millar model seen in figure 1 is used to form the theoretical framework in this study. The model was created during the LSE-project to evaluate worksheets in laboratory work. The model can also be used to analyze the effectiveness of a laboratory activity. The framework consists of four different steps A-D. The starting point (A) is to investigate the teacher’s purpose with the lab, what he or she wants students to learn. The next step (B) is to analyze the design of the task. What are the students expected to do. These two steps are influenced by the teacher’s view of science, teacher’s view of learning and in some extent limited to the practical and institutional context. What the students then actually do step (C) can then be observed during the activity. The last step (D) is to analyse what the students learned from the preformed lab work. Step (C) and (D) are in their turn influenced by students’ view of science and their view of learning.

The activities’ effectiveness can then be analyzed from two aspects: 1) what the students’ should do in relation to what they actually do. 2) Student’s learning outcome in relation to the teacher’s intention. The most fundamental purpose of laboratory work is that students shall be able to connect what they see and do in practice, to develop the scientific understanding (Tiberghien, Veillard, Le Marechal, Buty, & Millar, 2001).
A laboratory exercise can be effective from the point of “doing”, which means that students do what the teacher intended them to do, and that students reflect on their observations using ideas the activity developed. In order to demonstrate that a lab is effective in respect to learning outcome, students must be able to describe what they have done and observed. They should also be able to discuss the lab using the ideas that it were meant to develop, or use these ideas in a different context (Tiberghien et al., 2001).

Figure 1. A model of the process of design and evaluation of a teaching/learning task
1.2 Purpose
The purpose with this case study is to analyse the meaning of effectiveness of a laboratory activity, in relation to students’ learning and experiences.

1.3 Research question
How is the laboratory work efficiency seen as:
- A comparison between teacher’s purpose of intended learning outcomes and the students’ learning outcomes expressed in interviews and written reports?
- A comparison of the activities that students are supposed to do and what they really do?

2. Method
A physics teacher and a class was invited and accepted to participate in an empirical longitudinal study, about the role of laboratory work in a Swedish upper secondary school. This enables research on how different forms of laboratory work influence students’ and teacher’s interaction, communication and also their learning processes. An intervention is done in sense that the design of the laboratory work is predetermined. The teacher will each semester plan and conduct three physics labs with different degrees of freedom within the framework of the project. The results presented in this article are based on analyses of the first observed laboratory work, where the teacher was asked to design a closed activity. Our definition of a closed lab implies that the teacher decides: Topic, Task, Hypotheses, Method, Materials and Equipment, Time and Place.

2.1 Data-collections
The teacher was interviewed about the purpose, aim and intended learning outcome before the physics lab was performed. The six groups with 19 students, which participated were video recorded when they carried out the laboratory work. One week after the laboratory work session, interviews were done with each of the five groups. Two months later the students completed a written posttest. The interviews were transcribed verbatim. The video-recordings were converted to a computer program for video-analyses (Transana, 2.42), and transcribed verbatim. The students written reports (one from each group) were collected.

2.2 Procedure and Participants
The study was conducted in a Swedish upper secondary school. The participating students attended their first year on a science program, in their first course in physics at secondary level. At the time of observation, the 19 students had just started working with the topic uniformly accelerated motion. The students took two lectures about this topic before the laboratory work. The teacher had showed the students how to draw a position-time graph when a student walked in front of the class. The teacher had also demonstrated how a motion detector works, and had distributed USB sticks to the students, so that they could save their readings for later analysis. The students had not previously conducted a practical activity on the topic. This was also the first time that they used a Computer Based Lab (CBL). The study is an intervention in the sense we have asked the physics teacher to plan three labs per semester which differ in degree of freedom, and this was the first one of these.

2.3 Ethical considerations
The students were informed about ethical guidelines from the Swedish Research Council, and had given their written permission to take part in the study. The research plan was also approved by an ethical committee for Swedish universities.

2.4 Methods of analyses
The laboratory work and the interview video recordings were analysed based on the Millar model. The student interviews and the written reports and the post-test were analysed by repeated readings to find categories for student experiences and learning outcomes. The teacher interview was analysed by repeated readings to find categories for teacher aims, purposes and reflections.
3. Data and findings

Data and findings presented here are based on excerpts from the transcribed interviews with the teacher and students and on the transcribed discussions between students during the labwork. The outline is structured in accordance with the map of the theoretical framework presented earlier. An intervention was made in the sense that the teacher was asked to plan and conduct a closed lab. The researchers did not have any opinions or influence about the labwork content. The choice of content was decided by the teacher alone and in line with the course planning. Students had no influence in the actual design concerning task, question, equipment or method; this was all decided by the teacher. All interviews were conducted in Swedish; therefore, all excerpts in this article have been translated. The analysis of the transcripts was made in the Swedish version. All names used in this article are fictitious.

3.1 Miller et al model A: The teacher’s objectives regarding students intended learning outcomes

The teacher expresses the purposes in different ways in different contexts. We have therefore chosen to show how the teacher expressed this in three different situations; during the interview before the labwork takes place, but also in the worksheet, which the teacher produced to support the students in the labwork, and finally the purpose the teacher expressed at the beginning of the lesson.

3.1.1 Purposes expressed during the interview with the teacher

The teacher was interviewed just before the lesson started. When the teacher was asked about the purpose of the exercise, the answer was quite comprehensive. The teacher expressed the intention, that the lab will give students some understanding of position-time graphs using computer-based equipment. At this point, the teacher did not mention anything about related physics concepts such as speed, velocity or acceleration. The teacher emphasised that the students should pay attention to distance and work with positive and negative direction.

Researcher: What’s the purpose of today’s laboratory work?

Teacher: The purpose of today’s lab is to gain some understanding of a position-time graph using the computer (3) hm think about what distance is, give a direction, what is positive? What is negative direction? And we will mostly work with positive direction today, so yes....

3.1.2 Purposes expressed in the worksheet

The teacher had translated and revised an instruction available on the internet. In the worksheet a more comprehensive and detailed purpose are expressed, compared to teachers purpose in the interview. According to the instruction, students in addition to analysing a movement also should be able to predict, sketch, and test position and speed as a function of time. Further on, they are supposed to understand the difference between speed and velocity. In the instruction the following could be read:

- Purpose
- Analyse the motion when you walk in front of the motion detector.
- Predict, sketch and test position as a function of time.
- Predict sketch, and test velocity as a function of time.
- What is positive velocity?
- What is speed?

3.1.3 Purposes expressed during the teacher introduction of the laboratory work lesson

All students were initially gathered in the classroom for introduction. The students had been divided into groups by the teacher and these were presented on the projector screen. The teacher handed out the lab manuals and began by asking if they remembered to bring their USB-sticks. The teacher then addressed the whole class and stressed that the important thing with the lab was to use and save data on the USB memory. The teacher also pointed out that accuracy was more important than working far ahead.
Teacher: What’s important today is that I want to get this with USB to work. And you, who don’t have one, make sure someone else saves for you. You are going to save your file today, so it’s important that your name is on the file. If you save a lab then it maybe says 001 or something. But then it should read your name there also, and please use you first name and family name, neat and tidy. I’d rather see that you might not do so much, but that it is carefully done.

3.2 Miller et al model B: What the students have to do

What the students have to do are expressed in two different ways. During the introduction the teacher mainly focused on telling the students how to use the computer equipment, how to find the relevant files and store collected data individually on their USB memories. The instruction informs the students more about what they are supposed to do, in terms of analysing the graphs and explaining different concepts to each other.

3.2.1 What the students have to do according to the teacher (during the introduction)

After informing the whole class about the groups and how to use the USB memory, the teacher continued by talking about the procedure. The teacher holds up the lab instruction and points at the top of the paper.

Teacher: “So what are we going to do then? Has everyone got a paper? We are going to do some laboratory work! You are going to get different far today….

...The first part you can read through and think a little bit about. The purpose is not to start experimenting up here but instead when you come to part one. It is then you are supposed to do something. So, you who are going to start need a ruler and some adhesive tape. It is not so very important that you put tape on exactly one meter, but approximately...

...If you are unsure just ask! I recommend you to read through the instruction when you come to the lab station. Discuss with each other, every one of you are going to do this, so help each other...

...And you! Do not save your file on the computer, but on your USB storage.”

Teacher did not say anything at all about how to interpret the graphs. There was no discussion whatsoever, about physics concepts like position, velocity and acceleration. The teacher never declared what physics knowledge the lab was supposed to contribute with. The teacher’s purpose with the practical work during the interview was not as detailed as the purpose written in worksheet. In front of the class, the teacher briefly read the first line of the purpose in the instruction. The teacher concentrated mainly on telling the students how to store collected data on their USB-sticks.

3.2.2 What the students have to do according to the worksheet

What the students were supposed to do is thoroughly expressed in the lab instruction. First the students were asked to think about how it looks in an position-time graph when an object is standing still, moving with constant positive velocity and moving with constant negative velocity. The succeeding tasks were divided into four parts. Each part consisted of several steps, informing the reader what to do next.

1. Introductory experiments – The students should get acquainted with the equipment and try to walk with constant velocity in front of the motion detector. The tasks under this section guides the students how to connect and use the motion detector.
2. Position as a function of time - The student task is to explain the slope of a graph and discuss what it means when the line is tilted up, down and the meaning of a horizontal line.
3. Velocity as a function of time. – The students’ task is to try and walk according to existing v – t graph. The students are asked to explain their motion and discuss and describe a motion
4. Students creates own graphs and challenge each other’s.

There was no instruction or explanation in the lab manual, how the graphs should be interpreted. The instruction guided the students through the activity in the sense that it informed them about what to do, but gave no information about how they would do it.

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3.3 Millar et al model C: What the students actually do

All groups started by reading the instruction. No group that were observed discussed how an position-time graph looks like when an object is standing still or moves with positive, negative velocity, as the students were supposed to, according to the instruction. All groups started out on part 1. They began by putting adhesive tape on the floor, to indicate 1m, 2m, 3m and 4m. Then they started to do the introductory experiments according to part 1 in the worksheet. Figure 2 is excerpted from the computer software. In this situation the students were standing in front of the computer screen and analysed how they should walk to get a similar graph as the one shown in figure 2.

![Position – Time graph](image)

**Figure 2.** Position – Time graph. File from the computer software supporting the Motion Detector.

Peter: How should you walk to get this graph?

*Mira:* It’s increasing here!

*Linnea:* First we go back!

*Peter:* First it stands still!

*Linnea:* Or.., yes, at first it stands still and then we [go backwards.]

*Peter:* [Then faster!] No, it is one meter up there you know, before it was downwards.

*Linnea:* Oh well

*Peter:* So we go up.

*Linnea:* But this is higher and higher positions. Therefore, we have to walk backwards.

*Peter:* Yes (4) it is

*Mira:* But if you stand still and then go back one and a half meter, or?

*Peter:* Mm.

*Mira:* [And then you stop]

*Linnea:* [This is no distance] this is two [and a half maybe]

*Mira:* [Then you stay on] there and then you go back, or what?

*Peter:* Mm

*Linnea:* [true]

*Mira:* [and then you stop] you

*Linnea:* Should we do it like a test?

*Peter:* What do you mean? Compare and see if we get the same or?

*Linnea:* Yes, I think so.

*Peter:* Yes.
The students were clearly focused on collecting necessary data and store it on their USB-sticks. The discussions and interpreting of the graphs only occurred when they had difficulties creating a satisfactory graph similar to the original. The students did not take advantage of the markings they made on the floor at the beginning of the activity. Instead they started a trial and error exercise, where they repeated and refined the motion until they were satisfied with the result. The blue graph in figure 3 shows how the students were supposed to walk and the red graph shows how they actually walked.

![Figure 3. Position – Time graph. File from the computer software supporting the Motion Detector.](image)

### 3.4 Millar et al model D: What the students actually learn

A week after the labwork the students were interviewed in groups. In an attempt to find out what the students actually learned, they first had to answer questions about what they thought the teacher wanted them to learn. Then the students were given the same graphs they worked with during the lab. The students were asked to interpret and explain how the motion looked like. During the interview the students were asked how they experienced the severity of the lab.

#### 3.4.1 Students’ thoughts about what the teacher intended them to learn

Students could not answer the question right away. After thinking for a while they come up with suggestions on what they believe their teacher wanted them to learn. One student pointed out that before the lab, they had received a similar homework assignment where they would draw a position-time graph and therefore assume that the teacher wanted them to do it on the computer instead. Another student continues by saying that the teacher probably wanted them to learn to use the computer program and understand graphs.

*Researcher: What do you think your teacher wanted you to learn?*

*Martin: Good question!*

*Martin: (3) We have before this been given homework too, to draw a position-time graph like this. So I don’t know [whether we would learn]*

*Lisa: [but both are]*

*Martin: do it on the computer*
Researcher: What was that? Please tell!

Martin: We would try and walk ourselves at home and then draw graph like the ones on the computer.
Researcher: Ok!
Lisa: But I think she wanted us to both use the computer program.
Researcher: Yes.
Lisa: and to understand position-time graphs.

3.4.2 Students’ analysis of the graphs in the interview

Copies of the graphs were handed out at the interview. The students were once again asked to explain how they interpreted the graphs and describe the motion. In the following transcript the students are analysing the same graph as in figure 2.

Researcher: Can you describe how the motion looks like?
Kent: It is actually standing still
Anna: yes
Kent: on one meter., for about yes one second you start to walk with constant velocity.
Anna: two seconds
Kent: Yes, two seconds
Researcher: How do you see that it is constant speed?
Kent: It’s [rectilinearily]
Erik: [Moves, yes]
Anna: There is a straight line
Researcher: But it’s straight line here too and there also
Anna: [But]
Erik: [They are]
Kent: [but it is constant] it is still constant moving not when
Erik: on where it goes back a few meters
Anna: So it’s a constant speed all the time on the different parts but you will see that it is moving because the line has a slope. There it’s still because the line is straight.

The students did not hesitate or ask each other how to explain the graphs. They used physics concepts like speed, constant velocity and the slope of the line to describe the motion. From this, it is clear that the laboratory work has contributed to their learning, in the sense that the students are feeling more comfortable interpreting graphs of this nature. Two months later the students answered a posttest individually, where they had to write down how they interpreted the same graphs once again. This test indicated that the students’ knowledge gain from the activity was consistent and established.

3.4.3 Students’ thoughts about the activities learning demand

Researcher: Were there any difficulties in the lab?
Linnea: It was not a difficult thing we did, but we knew what we would do so. I do not understand why we would go from one meter two meters three meters [and four meters]
Peter: [No, it is the same thing]
Linnea: Why did we not just walk away from four meters and get a clearer result.
Researcher: Yes
Linnea: [We did this before]
Peter: It did not feel like there was any meaning to do this lab. [It felt]
Linnea: [No] we didn’t do anything!
Researcher: You thought this was a little harder a little more challenging you said with velocity-time graphs.
Emma: mm  
Hampus: Yes, it’s [difficult to keep the same speed]  
Mathias: [Keeping the same speed]  
Researcher: But the challenge, was that it’s difficult to go according to the graph or?  
Emma: mm.  
Mathias: yes, to stick to the graph exactly  
Emma: It was not difficult to understand the graph, so to speak  
Researcher: No  
Emma: [but it was difficult to do the same]  
Mathias: [but the difficult thing was to accomplish it]

The students have in general obviously difficulties explaining what they were supposed to learn from the activity. Some of them think out loud and comes up with possible suggestions during the interview. No students in the group could recall hearing the teacher talking about what they were supposed to learn. All groups could without any problems describe what they had done. The students in general experienced the activity as easy and that the learning demand was fairly low.

3.5 The laboratory works effectiveness from two different aspects

The laboratory work effectiveness can be analysed from two perspectives based on the Millar model. Level 1 is the relation between what the students actually do (C) and what the students should do (B). Level 2 is the relation between what the students learned (D) and the teacher’s objectives (A). The effectiveness of the practical work in this case study is based on analyses and comparisons of the video recorded observations, interviews, students’ lab reports and a posttest.

3.5.1 What the students actually do in comparison to what the teacher intended them to do.

Based on the observations it is clear that the students learned how to use the equipment and carry out the procedures involved. The students used the motion detector and the computer program and generated the kind of data in accordance with the teacher’s intentions. The students mainly followed the given instruction and observed the effects the teacher wanted them to see. When the students interpreted and discussed the graphs, they talked about velocity. Some of the students also talked about velocity in terms of its slope. Most of the students could even though, not explain the purpose with the activity. Overall the laboratory activity was effective in the sense that the students did what the teacher wanted them to do.

3.5.2 What the students learn in comparison to what the teacher intended them to learn.

At the time of the interview, the most students could in detail describe what they had done. Several of the groups discussed and explained problems they had encountered during the lab. Two months after the observed laboratory activity the students answered a posttest, where they had to draw a position-time graph based on a described motion. They were also asked to study and explain a velocity-time graph. Both questions were similar to the one they worked with before. The result of this posttest together with analyses of students’ lab reports indicates that a majority of the participating students have gained knowledge, how to interpret different types of motion graphs. They have also developed physics concepts like velocity, acceleration. This indicates that the laboratory work was effective also at level 2.

4. Discussion and Conclusion

4.1 Answering research question

The observed laboratory work was effective according to the Millar model. A deeper analysis of the activities effectiveness gives a more complex picture. Jacobsen (2010) claims that if the teacher declares what the students are supposed to learn from an activity, it will have a positive impact on students’ learning outcome. The teacher never told the students what they actually were supposed to learn by doing this lab. Despite of this, the laboratory work was effective at level 1 and level 2. The students’ learned what they
were supposed to learn; even so they had difficulties explaining the teacher’s intentions with the activity. It appears that the teacher had several purposes with the lab. In the interview, the teacher expressed a modest purpose compared to that in the instruction. Analysis of the introduction lesson shows that the main purpose for the teacher was neither of these, but instead letting the students learn how to use the equipment. The teacher’s purpose according to the worksheet became in this case more or less a disguise, for letting the students learn how to use the computer software. By doing this laboratory work, the students probably learned more about how to use the equipment by working through the physics tasks, than they learned physics by using the equipment. This was also in accordance with the teacher’s underlying purpose. What the teacher say, obviously have a huge impact on the students. In this case the teacher underlying purpose was perceived by the students and influenced the way they conducted the practical work. Most of the students’ experienced the laboratory work as easy and some even said that it felt like it did no difference.

4.2 Conclusion

The new Swedish syllabus stresses the importance of laboratory work. According to Gy11 (Skolverket, 2012), the students should be given opportunities to formulate and answer questions, plan and carry out observations and experiments. This requires that the degrees of freedom within the laboratory work increase. One possible way to accomplish practical work with the right learning demand is to involve the students in the planning; another way is to change the degrees of freedom within the laboratory work. A more open lab, claims higher demands on the students and requires them to take more responsibilities. A more open lab also causes the students to reflect more (Berg, Bergendahl, Lundberg & Tibell, 2003). In this case study the teacher decided the question, method and gave the students a thoroughly written instruction. The outcomes from this activity are to some extend in accordance with Roth (1996), which implies that this closed activity mostly concerned, learning how to use the equipment. At the same time the analysis shows that students also fulfilled the purpose according to the instruction. The teacher thought the student would experience the practical work as easy. The students’ also confirmed this during the interviews. The only difficulties students encountered, was to get their graphs match the originals. The overall learning demand can therefore be considered as fairly low. Some students also mentioned that they did not feel, as if this labwork contributed to their learning. A conclusion from this case study is that the effectiveness of a laboratory activity is influenced by more variables than just a comparison between the learning outcomes and the teacher’s intentions of these outcomes.

Learning outcomes is generally based on knowledge, understanding and skills. Though, “doing physics” by walking the motion- graphs as in this lab activity, seems to give some embodied knowledge, which the students cannot directly express as learning, but still refer to when they show their understanding of the physics principles later on. According to von Aufschnaiter, C. & von Aufschnaiter, S. (2007) students’ experiences are of great importance for effective teaching. Instead of searching for experiments that demonstrate a specific concept, instruction should focus on good learning experiences (von Aufschnaiter, C., & von Aufschnaiter, S. 2007). The result from this case study infers that analysis of the effectiveness also needs to take students’ experiences and embodied learning of the activity into consideration. Domin (1999) also claims that to better understand the effectiveness of different styles of laboratory work, researchers must go beyond the general learning outcome and student achievement. One fruitful way could be to adapt principles concerning good learning based on Gee (2005). These principles are divided into three main categories: Empowered learning, Understanding and Problemsolving. Transforming and defining these categories from a physics laboratory work context, could be a possible way to more accurate analyse the effectiveness of laboratory work, by extended the view on learning outcomes.

It is crucial to get the learning demand exactly right, if the students are supposed to feel involved and appreciate the activity. This requires that the teacher knows exactly what pre-knowledge the students have and can take that under consideration when planning the laboratory work. This implies that the circles in Millar’s model (figure 1); representing students’ influences also should be pointing towards “Teachers Objectives".
To deepening the meaning of effectiveness of a laboratory work the learning outcomes and the learning process need to be analysed from the students’ perspective, to relate student experiences to meaningful learning.

References


Informal Learning in CLOE Labs to Build the Basic Conceptual Knowledge of Magnetic Phenomena

Sri R. C. Prasad Challapalli, Research Unit in Physics Education of the University of Udine, Italy
Marisa Michelini, Research Unit in Physics Education of the University of Udine, Italy
Stefano Vercellati, Research Unit in Physics Education of the University of Udine, Italy

Abstract

Developing formal thinking and building conceptual knowledge as a background for formal interpretation of phenomena is one of the main challenges in teaching and learning physics. In the context of the experimental exploration of the electromagnetic phenomena, were investigated the pupils’ conceptual referents and representations of the phenomena and how they identify and explore conditions to produce electromagnetic interactions. Through semi-structured interview in framework of the Conceptual Laboratories of Operative Exploration, pupils construct global interpretations of phenomena starting from local interpretations of the single experiments synthetizing formal abstract entities in a qualitative early stage.

Introduction

Developing formal thinking and building conceptual knowledge as a background for formal interpretation of phenomena is one of the main challenges in teaching and learning physics (Michelini & Cobal 2001). In particular, in the context of the investigation of the magnetic and electromagnetic phenomena, where the interpretative quantity (the magnetic field with its variation) has a formal description that is a synthesis coming out from set of several observations concerning measurable quantity, is one of the main field in which the construction of the formal thinking play a crucial role. This construction will be performed as a gradual growth of the phenomenological condition to the occurrence of the phenomena, the individuation of the quantities involved, and the phenomenological exploration at the primary and middle school levels.

Research literature review, in physics education highlights the presence of several typical conceptual knots in the students’ knowledge related to the concept of field: the concepts of field as a superposition (Rainson & Viennot, 1992), the field representation (Guisasola et all, 1999) and the relation of the field lines with trajectory followed by bodies (Tornkwist et all, 1993), the relation between magnetic field and electric currents, the nature of field itself (Thong and Gunstone, 2008), the sources of field and the role of relative motion, Lorentz force and the presence of moving charges inside the conductor (Maloney et all, 2001). Indeed, students have difficulties in the determination of the verse of the induced magnetic field (Bagno, Eylon, 1997).

The pivotal role of the experiences, was highlighted by Duffy and Jonassen (1992) and Gilbert (1998) show that pupils construct spontaneously their own models to interpret the reality by observing of the world in their everyday life. It may create, in the prospective of the construction of the knowledge, the presence of persistent conceptions in pupils’ knowledge that may constitute difficult barriers to overcome (Duit, 1991) So the bridging between the scientific and the everyday knowledge is one of the main problem in the scientific education (Pfundt & Duit, 1993). It is therefore necessary, to provide to pupils contexts of experimental exploration in which informal hands-on and minds-on workshop activities take place with the aim to involve them in the process of the construction of knowledge to extend pupils’ experiences of the world and providing key activity strictly related to the main learning knots knowledge allowing them to address them effectively (Michelini, 2005).

With this prospective, the Cognitive Laboratories of Operative Exploration – CLOE – (Michelini, 2005) were designed and carried out by a researcher on specific topics. In particular, as concern electromagnetism, the researcher perform the lab following a semi-structured interview protocol, which represents an open work plan that allows to follow the pupils’ conceptual paths on the basis of the incentives offered. Initially pupils’ naïve ideas are investigated regarding the highlighted usual conceptual knots, then, by means of experimental and/or operative proposals, the phenomenology is investigated.
The following research questions are investigated: 1) How pupils identify and explore conditions to produce electro-magnetic interactions; 2) Which sort of quantities are conceptual references for the pupils for the representation of electromagnetic phenomena; 3) What kind of formal representations are adopted by pupils in the interpretative processes.

**Methods**

Cognitive Laboratory of Operative Exploration (CLOE) were performed with the aim to investigate how pupils develop their interpretative ability to explain situations and artifacts from the results of several simple phenomenological investigations. CLOE labs were developed to study and then to reinterpret the single experiment in the pupils’ process of creation of a global theory (Fedele et al, 2005). Carried out by a researcher on a specific topic, they are an open work environment, they are aimed to follow pupils’ conceptual paths through semi-structured interview protocol(s).

The first phase of this specific CLOE lab was carried out as a semi-structured big group discussion, focused to attract the pupils’ interest and attention and create resonance between the phenomenology addressed and the students’ naive ideas describing and explaining phenomena through the use of simple words.

The second phase, was a series of small experimental observations related to simple examples of interaction between magnets carried out by pupils promoting discussion by means a semi-structured inquired based discussion aimed to introduce an early representation of the magnetic field line.

The third phase was carried out in small groups: during this phase pupils face a real challenging task concerning the exploration of the conditions needed to produce an induced electromagnetic phenomenon. Pupils explore and interpret the phenomena taking into account all the observations carried out before trying to refer to them to provide an explanatory framework of the phenomena.

Then, the final discussion was focused on the sharing and the comparison of the different results obtained by the different groups to construct a shared explanatory model of the experimental situation proposed.

The semi-structured protocol was a guideline that could be followed or modified by the researcher based on the pupils needs, hypothesis and discussions.

The experimental activity was held in the building of the Faculty of Science Education of Udine in the context of a science fair ‘J-GEI’ (Giochi Esperimenti Idee – Games Experiments and Ideas). The investigation involved 17 classes of pupils from 6 to 13: eleven primary school classes (grades 1 to 5; 6 to 10-year old), six lower secondary school classes (grades 6 to 8; 11 to 13-year old). A total of 201 primary and 114 lower secondary school pupils were involved and participated at the experimentation. With the aim to promote the discussion between the components of the class as much as possible, the sharing and the comparison of the different ideas are encouraged. Data were collected only using audio/video recording of the activities.

Table 1 represents schematically the interview protocol that the researcher used during the first phase of this activity: the order of the experimental situations and the key questions that had to be proposed to the pupils was not mandatory, but the researcher had to follow the pupils reasoning, this choosing which order to adopt.
Table 1. Semi-structured interview protocol

<table>
<thead>
<tr>
<th>Protocol steps</th>
<th>Key question(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Recall pupils’ everyday knowledge</td>
<td>Q1 Which of you has a magnet at home? Illustrate some examples of magnets.</td>
</tr>
<tr>
<td>2) Recognize magnets from other objects</td>
<td>Q2 Having a collection of objects in a box, which one(s) are magnets? Explain how did you (operatively) individuate the magnets</td>
</tr>
<tr>
<td>3) Ferromagnetic interaction with a magnet</td>
<td>Q3 Having a magnet and a series of metals, which of them interacts with the magnet? Explain how to identify which ones interact with the magnet</td>
</tr>
<tr>
<td>4) Reciprocal interaction between a ferromagnetic object and a magnet. Planning an exploration</td>
<td>Q4 Does the magnet attract iron or does iron attract the magnet? Propose an experiment to test it</td>
</tr>
<tr>
<td>5) Interaction between two magnets</td>
<td>Q5a Take two magnets. How do they interact with each other?</td>
</tr>
<tr>
<td></td>
<td>Q5b Do magnets need to be in contact to interact?</td>
</tr>
<tr>
<td>6) Interaction between a magnet with another suspended</td>
<td>Q6a Hang a magnet to a pole and rotate the shaft. How does the hanging magnet react? Explain how does hanging magnet react another magnet when approaches it?</td>
</tr>
<tr>
<td>7) Compass as an explorer of the magnetic field</td>
<td>Q7a Place a compass on the table. Rotate it. How does the needle of the compass behave?</td>
</tr>
<tr>
<td></td>
<td>Q7b How could you turn the compass needle?</td>
</tr>
<tr>
<td>8) Compass as an explorer of the magnetic field</td>
<td>Q8 How does the compass needle rotate when it is placed close to a magnet. Describe what you observe.</td>
</tr>
<tr>
<td>9) A criterion to recognize the magnetic objects</td>
<td>Q9 Using a compass, can you identify which objects produce magnetic property in the space around it? How?</td>
</tr>
<tr>
<td>10) Identification of other magnetic field sources</td>
<td>Q10 Only the magnets have the property to create a magnetic property in the space around it (magnetic field)? Do you know any (other) objects able to do the same?</td>
</tr>
<tr>
<td>11) Electromagnetic induction</td>
<td>Q11 As we saw in the previous experiment, a wire carrying an electric current generate a magnetic field. Investigate if is possible to achieve the reverse process: can you create an electric current using a coil and a magnetic field?</td>
</tr>
</tbody>
</table>

Data and Results

The audio video recording of the dialogues were analyzed as reported in Figure 2: the role of the different interventions by the researcher (first row) and the pupils (following rows) is represented with a color code which identify each category of intervention, while the bottom row indicates the key question of each intervention is referred to: red for the key questions (the ones reported in Table 2), yellow for the additional questions designed to promote further discussion, blue for the interventions that are related to experimental situations, green for answers that are based on previous knowledge without referring to a particular experimental situation, orange for the discussions, and grey if there is a waiting time before the next sentence or question.

The way in which pupils intervention are reported in this schema reflects the way in which the discussion usually evolves in almost all the CLOE activities performed. Especially, with the younger pupils, there is an emerging group of some pupils (4 or 5 at least) that lead the discussions and are more active than other in the learning process. For example in Figure 2, we notice that for the 10-year old class, 4 pupils (over 18) did almost one third of the interventions and the remaining part is equally divided between group (coral replies, in which pupils answered all together) answers and answer given by pupils that did not do more than two or three interventions.

Looking for instance at the types of the pupils’ interventions reported in Figure 2, it is manifest how, with the development of the laboratory, the answers of the 10-year old pupils categorized as simple answers decreased (color green), leaving more rooms to the ones that refers to experimental situations (blue) and discussion/argumentation (orange). This trend is less marked in the 13-year old pupils where the green interventions occur through the learning path but especially emerge in the phase of experimental exploration of electromagnetic induction.

The time spent on the different experimental situations and the number of interventions done by the pupils depends on the complexity of the proposed experiments and size of the set of different interpretations that they proposed, but a general observation is that the lower secondary school student spent less time in the analysis of the single experiment than the primary pupils.
So, from the data acquired, especially from the ones of the 10 years old pupils, an important role of the partial and local interpretation of single experiment explored step by step emerge in building a global interpretation of the electro-magnetic induction phenomena, where interpretative aspects are recalled in an analogical way. Abstract entities are used during the learning path when inquired base hands-on and minds-on was carried out. The re-use of same quantities in a new framework is an additional gain of the coherent explorative chain in its own progress. For example, pupils refer to the property of the space surrounding the magnets, in few cases, a first representation of this magnetic property using compasses as explorer of the space, drawing a first representation of the magnetic field lines.

Figure 2. Example of analysis of a discussion

As previously remarked, the order and the type of activity proposed was not mandatory and in particular the different classes followed different learning paths; the learning paths followed are summarized in table P3.3

Table 2. Summary of the learning path followed by each group

<table>
<thead>
<tr>
<th>Type of School</th>
<th>Class</th>
<th>Followed Learning Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>2°</td>
<td>Q1, Q2, Q3, Q5, Q4, Q7, Q8, Q11</td>
</tr>
<tr>
<td>Primary</td>
<td>2°</td>
<td>Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q11</td>
</tr>
<tr>
<td>Primary</td>
<td>2°</td>
<td>Q1, Q2, Q3, Q5, 6*, 5*, Q6, Q7, Q11</td>
</tr>
<tr>
<td>Primary</td>
<td>4°</td>
<td>Q1, Q2, Q3, Q5, Q6, Q7, Q11</td>
</tr>
<tr>
<td>Primary</td>
<td>4°</td>
<td>Q1, Q2, Q3, Q5, 5*, Q6, Q7, Q11</td>
</tr>
<tr>
<td>Low. Sec.</td>
<td>2°</td>
<td>Q1, Q2, Q3, Q4, Q5, 5*, Q6, Q8, Q10, Q11</td>
</tr>
<tr>
<td>Low. Sec.</td>
<td>3°</td>
<td>Q1, Q2, Q3, Q5, 14*, Q7, Q11</td>
</tr>
<tr>
<td>Low. Sec.</td>
<td>3°</td>
<td>Q1, Q2, Q3, Q4, Q5, Q6, Q10, Q11</td>
</tr>
<tr>
<td>Low. Sec.</td>
<td>3°</td>
<td>Q1, Q2, Q3, Q4, Q5, Q6, Q9, Q10, Q11</td>
</tr>
</tbody>
</table>

A general trend highlighted in almost all the experimentation is the need to introduce an extra experiment into the learning path (labeled 5*) in which pupils explore the interaction between two magnets floating on the water - so they are free to rotate and rearrange themselves freely. The role of this experimental situation was crucial for the pupils of all levels, in particular, allowing them to determine the range of magnetic properties of the magnets. The pupils argued that even though we are not able to detect these properties, this does not mean that the property of the magnet are only in the surroundings of the magnet, but even if the magnet has a small entity it could be felt far away from the magnet.

Regarding Q11 (exploration of the electromagnetic induction), pupils were able to detect several different ways to produce current and all groups highlighted the transient nature of the phenomena, the set of movements of the coils that generated a current in the circuit with the exception of the rotation of the coil between the magnet that was highlighted only by 2 primary and 3 lower secondary school classes, its dependence on the velocity with which the coils moved, and the role of the orientation of the coils with...
respect to the magnets. Regarding this last point, two lower secondary school classes and one primary class highlighted that the orientation of the coil is related to the “direction of the magnetic property present between the magnets” (where the direction of the magnetic property is the direction assumed by the compass needle in the considered area) and in particular, “there is more current in the circuit when the coil and the direction of the magnetic properties are perpendicular and null when they are parallel”.

Conclusions
The results of this experimentation, show manifestly the necessity to introduce in the proposed learning path a specific experiment to allow pupils to explore the extension of the magnetic property of the object giving them an experimental idea of the extension of the magnetic field that goes beyond the simple observation done using the needle of the compass. Whit it, the learning path provides to pupils a set of experiences and observations that allows them to explore experimentally the phenomenology of the electromagnetic phenomena to provide a first explanatory model. This model, even if only in qualitative terms, was adopted by the pupils, to explore the phenomenological characteristics using as referencing physical quantity the idea of magnetic field. So pupils explored the main phenomenological characteristic of the process of the electromagnetic induction highlighting the dependence from such parameters highlighting the presence of a main direction in the structure of the magnetic field.

An important role of the partial and local interpretation of single experiment explored step by step emerge in building a global interpretation of the electromagnetic induction phenomena, where interpretative aspects are recalled through analogies. Abstract entities are used during the learning path when inquired base hands-on and minds-on activities were carried out. The re-use of same quantities in a new framework is an additional gain of the coherent explorative chain in its own progress. For example, pupils refer to the property of the space surrounding the magnets and performed a first representation of this magnetic property using compasses as explorer of the space.

References

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International Masterclasses Hands-on Particle Physics
The Portuguese Approach

M C Abreu, Laboratório de Instrumentação e Física Experimental de Partículas,
P Abreu, Laboratório de Instrumentação e Física Experimental de Partículas, Instituto Superior Técnico, Universidade Técnica de Lisboa
F Barão, Laboratório de Instrumentação e Física Experimental de Partículas, Instituto Superior Técnico, Universidade Técnica de Lisboa
J Carvalho, Faculdade de Ciências, Universidade de Coimbra
A Guerreiro, A Maio, Laboratório de Instrumentação e Física Experimental de Partículas, Departamento de Física, Universidade de Lisboa
A Onofre, Laboratório de Instrumentação e Física Experimental de Partículas, Universidade do Minho
L Peralta, Laboratório de Instrumentação e Física Experimental de Partículas, Departamento de Física, Universidade de Lisboa
A Pereira, Instituto Politécnico de Bragança
M F Mota, Faculdade de Ciências, Universidade do Porto
M G Pereira, CITAB, Universidade de Trás-os- Montes e Alto Douro
R Potting, Faculdade de Ciências e Tecnologia, Universidade do Algarve
J Santos, Instituto Politécnico de Beja
J L Santos, Faculdade de Ciências, Universidade do Porto
S Soares, Laboratório de Instrumentação e Física Experimental de Partículas,
F Veloso, Laboratório de Instrumentação e Física Experimental de Partículas, Faculdade de Ciências, Universidade de Coimbra
J Veloso, Departamento de Física, Universidade da Beira Interior

Abstract

Teaching and learning in an informal setting is a very effective approach to motivate students to study physics. The International Masterclasses Day in Particle Physics is one of a very important initiative in this context. The aim of the International Masterclasses Hands on Particle Physics is to bring high school students to universities and to immerse them in the mysteries of particle physics. After attending lectures and analyzing real data collected at CERN (Centre Européan pour la Recherche Nucléaire) in one of the participating institutes, students participate in a video-conference together with students from other institutes and countries, as is common practice in international research collaborations, to discuss their results. Since 2011 the students analyze data collected by experiments at the Large Hadron Collider (LHC) at CERN. Portugal, through LIP, participated in the launching of the International Masterclasses in 2005, during the celebration of the International Year of Physics. Since then the activity has enjoyed a sustainable growth. The 2012 edition involved 11 sites and 13 days, with nearly 2000 students and 200 school teachers, from all over the country. Since 2010 Portugal is the country with the highest participants in the program. In this article we describe our approach to organize the Masterclasses Day and identify some points which, in our opinion, are the key to the success of the initiative in Portugal.

1. Introduction

The authors are strongly convinced that teaching and learning physics in informal settings is a great way to bring valuable young people for science and in particularly for physics. This capability to attract teenagers is very important for our society as referred by several authors, e.g. Bell (2009), Sjöberg S and Schreiner C (2006), and is in line with our analysis of former activities in our country Abreu (2007). The authors have been responsible for the organization of the Masterclasses and some of them have even been involved in its editions since first, back in 2005. As a matter of personal experience, it is important to emphasize that some of us choose to study physics someday because an outreach action somewhere in secondary school days revealed that Physics is much more than what was taught in the classroom.

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For sure, this kind of approach can be used in any science field. As particle physicists we put our effort into showing students that there is a wide range of opportunities in this area, well beyond the scope of high-school curricula. This is equally important for secondary school teachers so that they don’t forget that science never stops and every day the frontier of knowledge moves forward.

Since particle physics is not a subject taught in every one of our universities, we have implemented a strategy based on sending some particle physics researchers to those universities to co-organize the Masterclasses at the local site. This new strategy enabled us to organize the activity in locations that are both geographically remote and less favored from the socio-economical point of view, without sacrificing the quality of the events. Travel distances and travel costs are considerably reduced, making participation possible for many students that would otherwise be excluded.

About 90% of the students attend the Masterclasses on Saturdays, voluntarily replacing the usual weekend leisure activities by research work. This demonstrates the excitement conveyed by this activity. We believe that this program gives students a strong motivation to learn and enjoy physics. They provide an insight into the physics state of the art and encourage young people to follow a scientific or technological career. In addition, students get a live experience on how international research work is done today in almost every field of science, resulting not only from the global nature of science, but also from the high cost of experimental facilities.

Besides, it clearly makes physics a less hermetic and more exciting branch of science for all the participants. And, in a certain way, make physics “democratic”, explaining why some investment in this field of science is justified.

In the next section we detail the approach followed in our country to facilitate student participation and reach the largest possible audience.

2. How to organize a Masterclasses Day

The CERN International Particle Physics Outreach Group (IPPOG) developed an educational activity with the goal of bringing the world’s largest scientific experiments into the classroom (http://ippog.web.cern.ch/). The International Masterclasses Day (MC Day) provides, as mentioned by Jende (2012) “an opportunity for high school students to be scientists for a day. Fifteen to nineteen year old students in countries around the world are invited to a nearby university/laboratory for a day in order to take part in an authentic research process.”

A typical MC Day starts early in the morning, with a welcome session around 9:00 AM, followed by two or three lectures. One of the lectures will give an introduction to the Standard Model of particle physics, the fundamental interactions, elementary particle and decay processes. Another lecture is dedicated to the physics at the LHC, accelerators and detection techniques. Some insight into data analysis is also provided, namely simple statistical concepts like mean, standard deviation, statistical and systematic errors etc. In some locations, a third lecture makes a bridge between particles physics and the local research. After this demanding morning a fast lunch is provided in the University cafeteria where informal discussions between the researchers and students take place. In the early afternoon the students are divided in groups of two, each group using a computer to analyze 50 collision events from a LHC experiment such as the “Compact Muon Solenoid” (CMS) experiment, the “A Toroidal Lhc ApparatuS” (ATLAS) experiment or the “A Large Ion Collider Experiment” (ALICE). The results obtained by all groups are compiled in order to be compared, by videoconference, with the results obtained in other institutions.

For students who wish to further exploit the subject, the CMS Collaboration prepared an additional CMS e-Lab for educational use in the classroom. See McCauley (2012) for instructions on how to use this kit.

2.1 The Portuguese Approach

In Portugal, the MC Day is organized by LIP (Laboratory of Instrumentation and Experimental Particle Physics) which is responsible for the vast majority of the experimental particle physics research in our country. The laboratory has presently three main sites (Coimbra, Lisbon and Minho). The number of scientists working at LIP is around 170, of which 70 have a PhD degree, many of them also being university
professors. The LIP main international collaborations are with CERN, Pierre Auger Observatory, GSI, ESA and NASA.

Portugal joined the MC Days initiative since its beginning, back in 2005. At that time the event took place only at three sites. In the first year the attendance was about 100 students (more or less equal number of boys and girls) and a dozen school teachers. Incidentally in the same year LIP started a school at CERN for high-school teachers, Abreu (2012), which helped to expand our contact network with high school teachers. There is clear evidence that after attending the CERN School the teachers feel more motivated to bring their students to the MC Day. Due to the high demand, contacts were established with universities throughout the country in order to motivate them to receive the MC Day event. As some universities don’t have research activities in this field we set up a Particle Physics mobile scientific team, including senior researchers and graduate students, which can help where needed. To better profit from the university infrastructures in most of the cases the MC Day takes place on a Saturday. To high schools that have a very limited travel budget, financial support is given by Ciência Viva (National Agency for Scientific and Technological Culture). The same agency supports the traveling and subsistence costs of the mobile scientific team. In other countries this kind of funding could be provided by the Education Ministry or local supporters.

At some of the sites, during the MC Day, students also have the opportunity to observe real cosmic rays with a Cosmic Ray Spark Chamber built by LIP, LIP (2010), and installed at the Masterclasses venue by the mobile scientific team.

The organizers keep track of the opinions of participating students with the help of questionnaires. The answers are taken into account when organizing future editions of the event.

2.2 The analyses performed in the Portuguese sessions

Since its beginning and up to 2010, the participants analyzed real data collected by the DELPHI experiment, one of the four experiments installed at LEP (Large Electron Positron collider) the previous large accelerator at CERN.

As data from the LHC experiments became available at the end of 2009, the analyses switched in 2010 to the use of the visualization and analysis programs based on ATLAS data (Portugal participates both in the ATLAS and in the CMS experiments), namely HYPATIA and MINERVA. With MINERVA, participants in a MC Day analyzed data with $W^\pm$ Bosons and their decay to final state particles. As a final challenge, the students were teased to identify events with a simulated Higgs Boson (decaying into pairs of $W$ bosons, which subsequently decay into (anti)lepton-(anti)neutrino pairs). With HYPATIA, participants analyzed data with $Z$ Bosons, to measure its mass from a combination of decay particle information.

As a challenge, they were also asked to identify a hitherto unknown peak caused by a simulated hypothetical boson.

In the HYPATIA program, the calculation of the invariant-mass is made simple by the program, in a way transparent for the user, so that it remains an option for the local tutors to explain the concept and the analysis techniques based on the mass spectra. In both cases, the change from DELPHI data taken at a clean $e^+e^-$ collider to the ATLAS/CMS/ALICE data from a proton-proton collider seemed risky and posed the challenge of what measurement could be made and understood in about one hour. But finally, with data samples built with specific criteria providing clean events, it was possible for the students to visually analyze events.

At the same time they understand that, because in a proton-proton collision the centre of mass moves along the beam axis with unknown momentum, the important variables are on the plane transverse to the beam axis (transverse momentum cut to get rid of hundreds of spurious particles, missing transverse energy to check the possibility of neutrinos and if the event is a $W$ boson, the angles measured in this plane to assess/increase the chances to identify correctly the simulated Higgs boson event, etc).

With LHC data, and now analyzing $Z^0$ boson decays as well as $W^\pm$ boson decays, the energy balance and the momentum conservation in the transverse plane became a crucial analysis tool. To select an event as

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a W boson event, students were required to look first to the variable MET (Missing Energy Transverse). Only if this value was higher than a certain threshold provided to the students, would they consider the possibility of having in the event an energetic neutrino coming from the decay of the $W^\pm$ boson. They must then proceed to identify the isolated energetic track and obtain its charge.

In the W boson analysis, the ratio of events with a positively charged W boson to a negatively charged W boson is also a telltale signal of the valence constituent quarks in a proton. This is also addressed in a subsequent discussion with the scientists supporting the activity and the moderators at CERN. As for the analysis of the $Z^0$ bosons, the students start by identifying a pair of energetic particles with opposite charge and behaving the same way in the detectors (that is, particles of the same type). Although the invariant-mass of those particles is computed by the program (HYPATIA), which also builds an invariant-mass histogram, the students are taught how to calculate this quantity, and learn its relevance and its importance as tool to discover new particles.

Actually, the $Z^0$ samples also include some simulated events with a new highly massive hypothetical particle $Z'$, that is to be “identified” in the invariant-mass histogram (as a peak near a very high value). The invariant-mass variable and its calculation also allow a glimpse on special relativity and invariant quantities (quantities that have the same value for different observers).

Both exercises do not require the mastery of calculation techniques or of technologies of particle detectors, as they are based on the visualization and discrimination capabilities of the human eye that excels in the search of particular patterns. After a simple and fast training the students were able to perform the exercises mostly in an autonomous way, with minor intervention from the monitor.

3. Data and Findings

The new strategy described in paragraph 2.1 brought clear improvements, namely an increment in the number of participants due to more favorable participation conditions for students and teachers. We are happy to see that the organization scheme adopted seems adequate to reach the proposed objective, namely to give the maximum number of students the opportunity to be in contact with a cutting edge topic in physics. As previously mentioned we started the MC Day in 2005 with just 3 sites and around one hundred students. In 2012, about 200 teachers and 2000 students were involved, an increase by a factor of 20 in just 8 years. The participation of both genders was approximately the same along all these years. In 2012 the event took place in 11 universities all over the country. For the first time secondary students and teachers from S. Tomé e Principe, an African country belonging to the Community of Portuguese Speaking Countries (CPLP), also participated in the event.
Figure 1 shows how universities, school teachers and students support this kind of learning in an informal environment.

![Temporal evolution of the numbers of participants and venues for all Portuguese participations in this initiative](image_url)

**Figure 1.** Temporal evolution of the numbers of participants and venues for all Portuguese participations in this initiative

The number of Portuguese participants in 2012 is quite impressive when compared with the other 25 countries involved in the initiative, as can be seen in Figure 2. Portugal is the country with the highest number of participants in the program since 2010. This is clearly the best reward we could hope for. However, it should be noted that some countries like Germany, and the UK, among others, organize other activities similar to the Masterclasses Day over the year, which are not reflected in this chart.

![Number of participants in each country during the MC Day in 2012](image_url)

**Figure 2.** Number of participants in each country during the MC Day in 2012

The figure 2 does not refer participants outside CERN member states, as for example, the United States of America or the first CPLP participation.

4. **Discussion and Conclusions**

A set of conclusions can be drawn from the analysis of the questionnaires filled in by the students after each session.

Students recognize that this day of “hands on” Particle Physics allows them to extend their knowledge on the structure of matter, a topic that in the high school curricula is limited to the proton, neutron and electron level. Equally important is the acquaintance they get with some basics of experimental data analysis, namely the need to acquire and analyze a large number of events when seeking for rare events.
The students also greatly enjoy the opportunity to be exposed to the university environment, for most of them their first contact of the kind. They are particularly enthusiastic about inter-school and international dialogue during the videoconference. Also mentioned in the answers is the opportunity to put challenging questions to CERN researchers and to show the good performance achieved in the data analysis.

We believe that this is an excellent example of informal learning and teaching in physics. Students’ attitude after the MC Day shows that they regard science in general as an appealing choice for their university options. On the other hand, school teachers are quite pleased to cooperate with scientists and some of them even start to develop some pedagogical research in this field. The cooperation between universities and schools is also reinforced by these activities. Obviously, the large number of participants in some universities raises serious logistic problems and it is difficult to deal with more than 100 students per day, although in 2012 two universities had received about 300 participants in each of the two occasions held at their premises.

In the near future we intend to further increase the number of participating universities, including those in the Portuguese islands of Azores and Madeira and support the implementation of the activity in the CPLP countries will be provided.

5. Acknowledgements

We want to express our gratitude to all high school teachers that participated in the event during all these years, as well as to the staff of all partner universities, the computer and videoconference staff in particular. We can’t forget the LIP postgraduate students that move around the country helping us. In the last year the Portuguese Physics Society and its Education Division in particular, was also an important partner in the motivation of teachers. Funding assumes a vital role in this activity and we are also thankful to the Ciência Viva Agency for their support.

Finally, to the LIP Workshop our gratitude for the work put in building a mobile, robust and nice cosmic ray spark chamber.

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Undergraduate Research -What is it?

Asim Gangopadhyaya, Department of Physics, Loyola University Chicago, 1032 Sheridan Rd., Chicago, Illinois 60660, USA

Abstract

Undergraduate research is now widely seen as one of the major paradigms for engaging students. In the US, undergraduate research opportunities have become a common expectation of almost all incoming students and their parents. By bringing together the experiences gathered by a large number of colleagues at leading undergraduate institutions, I will describe the general understanding of undergraduate research. At Loyola University Chicago, for the last sixteen years, we have been engaging students in research from the very beginning of their careers. I will discuss this innovative Freshman Research Program, which has become a segue for many to more advanced undergraduate research at Loyola, and is making a profound impact on our program.

1. Introduction

At the 2003 meeting of American Association of Physics Teachers (AAPT), Steven Weinberg stated that when he graduated from Cornell, he was a good student, but not a good physicist. As he explained later, he meant that he had no idea how one carried out research without first knowing all that was known in the field of physics.

This is a very telling statement. It clearly shows the need for introducing elements of research into our undergraduate curriculum. Incorporating research would not only prepare them well for graduate education, but would also help students engage with a faculty member, and focus deeply on a particular project, and critically analyze various facets of the problem.

Undergraduate research (UG) has become a vehicle for deeper, more engaged learning. With the sense that education is becoming increasingly expensive, it has also become an expectation of parents that students will receive opportunities for research and internship during their undergraduate education at private or public universities. As a result, many universities now explicitly advertise the various ways in which they would engage incoming students during their formative years. According to Guterman (2007), “The National Science Foundation spends some $50-million yearly to support about, 500 students just in its largest undergraduate research program, the summer Research Experiences for Undergraduates. The Howard Hughes Medical Institute supports an additional 3,300 students. Over all, some 40 percent of students majoring in the life sciences and physical sciences do research with a faculty member, according to two surveys: the National Survey of Student Engagement, which canvassed more than 65,000 students at 209 colleges and universities, and a study performed by the Reinvention Center, at the University of Miami, which surveyed administrators at 75 research universities to get estimates.”

To some extent, this pressure to introduce research at the undergraduate level had left many of us somewhat bewildered. Even today, there is still quite a bit of confusion as to what exactly constitutes undergraduate research. In Sec. 2, I will describe some of the common understanding of undergraduate research, much of it is based on our experience at Loyola University and from talks given by several authors at various conferences (Dawkins, Mathieu & McCormick, 2010), (Gentile, 2007), (Hilborn, 2001), and (Sudhakaran, 2009).

In Sec. 3, we describe the undergraduate research program at Loyola University Chicago. In the physics department at Loyola, we now have a highly developed structure for involving students through project-based learning. We started our program well before the current trend, and have been continuing it for the last sixteen years. We require that all our students participate in at least a one-semester-long undergraduate research experience beginning no later than the second semester of the freshman year. These are called freshman projects. Many students continue this research beyond their freshman year.
In appendix A, I list some of the recent projects of our students. In appendix B, to provide an explicit example of how freshmen projects develop into more advanced research topics, I have attached a poster from a conference attended by two of our students. It shows the maturation of their research through the four years of their undergraduate education at Loyola. In appendix C, I have attached a brief description of a national study of the impact of undergraduate research on students at predominantly undergraduate universities (Guterman, 2007), (Hilborn, 2003).

As is well known, these are very time consuming endeavors. Most universities do not yet have a mechanism to give the appropriate credit to students and faculty members for their tremendous work in running these projects. It is crucial that upper administration supports such ventures. Without full support from the administration, it is almost impossible to find sufficient resources for research, and to provide the necessary teaching reduction for faculty members that that are fiercely active in mentoring students. I will describe some of the steps we have taken to incentivize these projects, and to allocate proper credit to students, as well as their advisers.

2. What Counts as Undergraduate Research?

Until very recently, the general perception was that undergraduate students were not capable of doing research. However, from the numerous conferences on this subject, it is becoming clear that the concept of UG research is taking hold.

According to Dr. Nancy Hensel (2012), the former executive officer of the Council of Undergraduate Research (CUR), the council has about 7000 members. CUR have put together a 72-page long monograph describing “Characteristics of Excellence in Undergraduate Research”. “It is based on the collective experience, over many years, of CUR members who have engaged undergraduate students in research, developed undergraduate research programs, mentored new faculty to include undergraduate research in their teaching repertoire, and coached universities in the development of undergraduate research programs... The instrument aspires to present the best practices in undergraduate research. It can be used as a guide for institutions that are striving to enhance the learning experiences of students through research program.” The monograph succinctly describes undergraduate research at many schools in various disciplines. It can be a great resource for schools/departments that are in the process of initiating an undergraduate research program.

While the meaning of research varies among disciplines, there are several concepts that are common to all programs. Here we describe some of the basic ideas that describe UG research, as we see them. 1

2.1 Define and promote research broadly

The word “Research” has to be understood in a rather broad sense. The process must have discovery associated with it. It could be as simple as a student (or a group of students) discovering various parameters that affect frictional force between two surfaces, or it could be a collaboration with a researcher in a big project publishable in a big named journal. Sometimes, at least in the initial stages, UG research may be not very different from glorified independent reading, or special lab projects.

To insure that student does not lose confidence in his/her learning, it is advisable to start small and build slowly. The level of research should grow with the student. In appendix A, we give a list of projects that our beginning students worked on during the last two academic years. The appendix B shows a particular project that turned into a research project which was presented at several professional meetings and is expected to lead to several publications.

2.2 Build Student Research into the Curriculum

If possible, require research as part of the curriculum. It can be done by embedding research projects into the courses for majors. In some schools, there is a thesis requirement that students must fulfill in order to get their undergraduate degrees in physics. For programs that require a thesis, it could be the culmination of research done over the undergraduate years. Many schools demand a capstone experience for their...
students, which could be a good place to introduce elements of research in case students haven’t had a chance to experience research earlier\(^1\).

While students should be encouraged to participate in long-time research projects, it is pedagogically more effective to scatter small research projects throughout the curriculum, and thus help build their research skills. This type of intentional incorporation of research opportunities will insure that a larger number of students get exposure to research methods. Since our textbooks are generally not designed for such open-ended project based learning, such modifications are generally very time consuming endeavors for faculty members.

2.3 Mentors Must Challenge Students and Empower them to Succeed

It is very important that faculty members make clear to their advisees what the expectations from the project(s) are. S/he should also make the student aware of the challenges, especially the possibility of not getting a publishable/presentable result.

The faculty member would need to keep in mind that building confidence in student must remain one of the main objectives. Even if a project does not generate exciting results, s/he will need to emphasize the skills that were picked up in the process and would be helpful to them later.

2.4 UG Research Must be Visible

One of the important aspects of undergraduate research is that it must be visible (Hilborn, 2001). By visibility, we mean that work must be disseminated via all possible avenues. Within the university, there should be research presentation days. Local chapters of the AAPT are good places for presenting undergraduate research. In bigger cities, there are local Undergrad Research Symposia for such presentations. Depending on the level of research, manuscripts should be prepared for undergraduate research journals, and if warranted, for well known peer-reviewed journals. We owe it to our students that their research be made available to the wider community.

3. Undergraduate Research at the Freshman Level

In this section, I will describe an innovative Freshman Research Projects program that we initiated at Loyola. All of our physics majors must have research experience through their first year experience in the department. We will describe how our projects got started, what their current objectives are and how they have affected our program.

3.1 Genesis

We started this innovative program in 1996. It was originally developed to engage students in deeper learning through research starting from their freshman year. But as we will describe below, it has helped us achieve many more goals. We have continued these projects, without break, for the last sixteen years. In 2005, our projects were featured in an article in the Chicago Tribune (Kapos, 2005). In 2009, we elevated this program to a required course so that students, as well as advisers, would get credit for their enormous time commitment.

3.2 Goals

These projects serve several goals.

a) First, they allow students to explore a single problem more deeply than is generally possible through a regular lecture-based course by engaging in research.

b) Second, students working in small groups develop closer relationship with other physics majors. As our majors work together and get to know their advisers, it also instills a sense of community among them. Under the watchful eyes of their mentors, students learn to work as a team.

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\(^1\) Since capstone courses are generally taken during the senior year, we prefer that research experience begin much earlier in their career.
c) Third, students, in collaboration with their faculty advisors, choose viable topics that match their interests and can be accomplished within a given budget. The project must have a thesis, must have a building component, a theoretical infrastructure, data collection, analysis of the data, and must have a presentation in a departmental symposium. Thus, with the freedom to design their own projects, responsibility of insuring that the project conforms to the constraints given, they are taking charge of their own education, and are encouraged to think creatively.

d) Fourth, the relationship they form with their adviser helps many students to go into more advanced research in later years.

e) Finally, these projects offer our students experience in oral and written presentations, and introduce them at an early stage of their scientific careers to the realities and excitement of exploring physics. In many cases these projects blossom into publishable research by the time they are juniors and seniors, and many of them present their work at local and national meetings of the relevant professional societies.

3.3 Description of the Freshman Project

3.3.1 Objective

The objective of the Freshman Projects course (PHYS 126F) is for students to develop and carry out research on a project that uses concepts covered in the introductory physics course for our majors, but that goes beyond the work done in a standard classroom. Potential physics majors in the introductory physics course (PHYS 126) are divided up into ten small groups with a maximum of 5 students per group. Students in each group choose a faculty adviser. Each group must submit a proposal outlining the goals of the investigation. They are required to keep a scientific notebook and document their work throughout the semester. Each group must design an experiment for the investigation, use our machine shop to build the necessary apparatus, develop theoretical infrastructure, carefully carry out the experiment, collect data, and carry out a systematic analysis to see whether their finding supports or refutes their thesis. Students are required to spend a minimum of 42 hours on these projects, but they generally invest many more than that. At the end of the semester, students create a poster and give an oral presentation at a specially arranged seminar that is attended by all faculty members and a large number of advanced students. In appendix A, a list of the projects from 2011 has been attached.

Some freshman projects have been presented at local and national meetings of the AAPT and undergraduate research conferences (specifically the Chicago Area Undergraduate Research Symposium and the Argonne Symposium for Undergraduates in Science, Engineering, and Mathematics). We believe that positive experiences with the Freshman Project encourage students to pursue undergraduate research opportunities beyond their freshman year.

In addition to giving freshmen very valuable research experience, the Freshman Project serves other pedagogical and social goals within the department. In one marvelous case, an advanced student took 15 freshmen under his wing and led them in a research project of his own. In a department with a relatively large undergraduate population, it may be difficult for students to become acquainted with the department faculty, especially before they have taken (generally smaller) upper-level classes. The Freshman Project provides opportunities for students to work closely with a faculty member early in their careers as students, and to become more acquainted with the department beyond their professors teaching introductory physics lectures and lab. It helps students develop collaborative learning skills. Additionally, working in small groups helps students to meet each other and to develop a sense of identity as a group of future scientists.

One way in which our program differs from many other undergraduate research opportunities is that the Freshman Project takes place in a student’s first year, as opposed to traditional undergraduate research and Research Experience for Undergraduate (REU) programs which frequently target students later in their

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1 Sometimes published in peer reviewed journals, and often presented at undergraduate research symposia and professional meetings.
career, often at the junior and senior level. As mentioned above, research performed during a student’s earliest years is essential (Hilborn, 2003).

Thus, we believe that the Freshman Project program has indeed brought students together with a sense of a scientific community, offered them experience in oral and written presentations, and introduced them at an early stage of their scientific careers to the realities and excitement of exploring physics outside of the textbook.

3.3.2 Integrating Technology

Another important goal of our freshman projects is to familiarize students with the technologies that scientists use to perform research and communicate scientific results. Developing an early fluency with these tools encourages their use throughout the students’ undergraduate careers and adds valuable skills to their repertoire as they prepare to enter the workforce or pursue graduate studies.

Students are encouraged to investigate their projects using software packages that practicing researchers use. To this end, the students use software like Mathematica, a general-purpose system for technical computing, or LabView, a simulation and data gathering environment.

3.3.3 Assessment

Students are evaluated based on the quality of the projects and presentations, as well as on their collaborative participation in the design and implementation of their plans.

3.3.4 Effect of the Freshman Projects on the Physics Program

As stated in the beginning, the Freshman Project experience at Loyola University Chicago began during the 1995-1996 academic year. From the very beginning, the main motivation was to provide an additional framework to get students engaged in deeper learning. At the time the Freshman Project was introduced, the LUC Physics Department was struggling to attract and retain students. In the mid-1990s, many physics departments experienced low enrollment, and Loyola was no exception (Hilborn, 2003). For the five years prior to the introduction of the Freshman Project (1991-1995), the LUC Physics Department graduated 24 students total, for an average of 4.8 per year.¹

Since the inception of the Freshman Project, the Loyola University Physics Department has experienced very strong growth. According to the American Institute of Physics (AIP), LUC was tied for the eighth largest average graduating class in the nation during the period 2005-2007 and fourth during 2006-2008, among bachelors-only departments, with an annual average of 17 and 22 graduating students respectively (AIP Statistics Tables, 2012).

3.3.5 Bridge to Advanced Research

Many of these freshmen go on to carry out further research during their sophomore, junior and senior years. In appendix B, we have described the work by Benjamin Irvine and Matthew Kemnetz that began during their freshman year in 2009. They have presented their work at various fora including two different national meetings of the AAPT. A manuscript describing their work is available at the physics archive (Irvine, Kemnetz, Gangopadhyaya & Ruubel, 2012). There are others students that have published papers in prestigious journals such as Physical Review E with my colleagues at Loyola.

Our experience shows² that students that go into research beyond their freshman year, generally go to graduate schools in physics or a related field after leaving Loyola.

3.3.6 Involvement of the Administration

As stated earlier, it is essential that faculty and administration both see undergraduate research as an important paradigm for engaged learning. Fortunately for us, the vision of our upper administration for

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¹ It is important to note that 4.8 graduate/year was about double of the national average. We are currently about five times the national average.

² This is contrary to the observation of Ref. [Guterman-2007].
The university - a place for an excellent undergraduate education - fits very well with our vision for a vibrant department with a strong culture of research with undergraduates. The administration has made available resources for several modest projects running simultaneously. It is specially noteworthy that through the Office of Experiential Learning, Loyola University provides a large number of scholarships to students engaged in undergraduate research. We have a special annual symposium for presenting undergraduate research. Every April, a large number of undergraduates from many disciplines present posters describing their research. Such efforts are essential for a culture of undergraduate research to emerge on a campus-wide scale.

3.3.7 Compensation for Faculty

Many of our members spend a substantial part of their week with students guiding them in freshman level research and beyond. During summers, when teaching loads are comparatively low, mentors spend an extraordinary amount of time in mentoring students. These faculty members cannot be adequately compensated for their noble effort, at least not monetarily. We have now elevated the freshman research projects into a course. Thus, students taking part in these projects receive academic credit, and faculty members get credit for mentoring. We also have courses designated as "Undergraduate Research", and advanced students can take these courses for up to a total of 12 credits. Mentors receive teaching credits if students register for research courses under their supervision. Involvement with undergraduates, especially research with advanced students, is taken very seriously in annual evaluations, and in promotion and tenure.

4. Conclusion

Undergraduate research is widely seen as one of the major paradigms for mentoring our undergraduate students (Guterman, 2007), (Gentile, 2007). In our attempts to provide a transformative educational experience for our students, we have identified undergraduate research to be one of the best ways to engage our physics majors. These projects not only bring research experience to our students very early in their career, and thus engage them in deeper learning, they also serve as gateways to more advanced research beyond their undergraduate education.

5. Acknowledgement

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Appendix A. Freshman Projects

Spring 2011

There is a coupling between vertical spring harmonic and angular simple harmonic motion. The purpose of our project was to study and create equations for this phenomenon using controlled experiments.

2. Analysis of Pianos: S. Adhikari, C. Choi, K. Filip, M. Guzman, and T. Jozefczyk; Prof. Gordon Ramsey
The purpose of our project is to understand how string vibrational and acoustical properties differ in grand and upright pianos. ···

3. Optical Response to Changing Water Droplet Shape: A. Bayrak, J. Minalt, N. Kuehnle, F. Uddin; Prof. Robert Polak
Use of water droplets to focus light into solar cells requires a consistent focal length. ···

This experiment studies the behavior of standing waves on a loaded ···

5. Introduction to Aerodynamics: The Effect of Shape, Size and Texture on a Falling Object’s Acceleration A. Jagadeesan, G. Pfaff, N. Pflederer, J. Thompson, Prof. Dr. M. K. Udo
We are interested in learning the effect of air drag on objects as they undergo free fall. ···

6. Preliminary Investigation of Wind Turbines and Solar Cells: A. Kepler, S. Kim, I. Kusmic, W. McDonald, E. Varty; Prof. Thomas Ruubel
We were interested in sustainable energy generation. ···

Several centuries after the first insights of Leonardo da Vinci regarding the behavior of sliding blocks, Amonton reported his experimental results on the dry friction force, which he found to be both independent of interaction and contact area and proportional to normal force, in the late 17th century ···

8. Study of Large Amplitude Oscillations: F. Giurgiu, C. Mcginty, J. Ross, Prof. Asim Gangopadhyaya
··· We also designed and studied a physical pendulum using a bicycle wheel with a mass attached to the inner rim of the wheel. We compared our observations with numerically obtained results.
Spring 2012

1. Physics of Rubens Tube: Alex Acosta, Gabriel Fuentes, Grace McClusky, Kirril Lavrenyuk and Ken Johnson; Prof. John Dykla

2. Study of Viscosity: Newtonian vs. Non-Newtonian Fluids: Tyler Bobella, Sarah McDowell, Joseph Sawicki, Derek Thayer; Prof. Jonathan Bougie

3. Electromagnetic Accelerator: Joseph Cecala, Aidan Klug, Luis Ortega and Andrey Puzanov; Prof. Asim Gangopadhyaya

4. Wave-Powered Generator: Robert Medina, Mark Peterson, Farheen Syeda, Dan Zimmerman; Prof. John Cunningham

5. The Physics of Banjos: Joseph Bella, Alex Gilman, Thomas Sullivan and Andrey Puzanov; Prof. Gordon P. Ramsey

6. Syringe Hydraulic robot: Matthew Durfee, Christian Konopka, Michelle LIs and David Sack; Prof. Maria Udo

7. Extracting Energy from Wave Motion: Joe Berce, Mary Bucki, Walid Syed and William Zhe; Prof. Robert Polak

8. Attempts at a Dyson: Air Multiplier Chris Camarata, John Markos, Shane Romer, and Nick Tilelli; Prof. Robert McNees

9. Photoelasticity and Stress: Ethan Blackburn, Aleksander Weismantel and Lukasz Zak; Prof. Thomas Ruubel

10. Static Friction Revisited: Zach Ganger, Paul Kleinmaier, Ahmed Safdar, Brian Stone; Prof. Aleksandr Goltsiker
Appendix B: Poster presented at 2012 spring AAPT meeting

This work began as Freshman Project in spring of 2009. Two students, Benjamin Irvine and Matthew Kemnetz carried out significant research in experimental and theoretical areas. The details of their work is given in Ref. (Irvine, Kemnetz, Gangopadhyaya & Ruubel, 2012). The following figure is a copy of the poster they had presented in 2012 Winter meeting of Am. Assoc. of Physics Teachers (AAPT) at Ontario, California.

Figure 1. Poster presented at 2012 spring AAPT meeting in Ontario, CA.

Appendix C: National Study of the Impact of Undergraduate Research

In a Physics Department such as Loyola’s, with its nationally-recognized, large, and diverse enrollment of physics undergraduate majors in an undergraduate-only Physics Department, research is essential (Hilborn, Howes & Krane, 2003). This has been recognized and documented in a series of studies. In 2003, the Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) released its final report in this regard. After conducting a national survey of undergraduate physics programs, SPIN-UP listed undergraduate research as one of the elements of a thriving undergraduate research Physics program (Hilborn, Howes & Krane, 2003). The report goes on to conclude that, Students gain experience working in teams and communicating their results, both orally and in written reports. The shared research experience gives the students a deserved sense of being part of the scientific community, not just passive consumers.

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of science through their courses. Most departments recognize the importance of undergraduate research in building a sense of community within the department (Hilborn, Howes & Krane, 2003).

Although it can be difficult to quantify the role of undergraduate research in regard to a students skill set and career choices, three large studies have attempted to shed light on this area (Guterman, 2007). These three studies each examined three different areas. One included in-depth interviews with students at four liberal-arts colleges. Another expanded this study for thousands of students at other institutions. The third study performed similar surveys with students, some of whom had received grants from the NSF for research. All three studies found similar cognitive and personal benefits for students, including understanding how scientists work, learning laboratory techniques, and gaining self-confidence (Guterman, 2007). And although it is difficult to quantify whether undergraduate research increases the likelihood of a student attending graduate school (some students in the surveys did find the reality of research tedious and difficult, and all researchers reported the difficulty in surveying students years after graduation), all three studies conclude that undergraduates learn and grow significantly from their research experiences.

References


**Abstract**

The Institute of Physics and its Didactics at the University of Cologne is engaged in developing frameworks for learning science in meaningful real-world contexts. Sample contexts are Climate Change, Road Security and Disaster Relief. A sample project within this framework is “Crash Kurs NRW”. This is a State-Wide Program in North Rhine-Westphalia (NRW), Germany where Policemen, Paramedics and Firemen visit Schools and present authentic reports of car accidents to a large audience (>200). Accidents are chosen to be local and to involve young drivers. In the follow-up program, students analyse the causes for accidents, which typically cover speeding, drug abuse, distraction, or improper use of safety belts. Thus, the reasons of all accidents can be argued using proper scientific reasoning. On an ICT platform, example lessons, aiding resources, and video footage for in-service teacher training have been made available. Additionally, the server is used as a platform for project evaluation. The various evaluations were made with 6 Police Departments, 18 Schools and 1400 Students in a pre-post study and will be shown and discussed in the article.

**Introduction**

1.1 Why do we teach physics?

The usefulness of physics as a school subject is sometimes questioned. Physics is difficult and boring for most of the students. So how can we make physics meaningful and interesting for the students without losing sight of the content of physics education?

1.2 Theoretical Approach

1.2.1 Authentic context for physical education

As said before, Teaching physics can sometimes seem to be very difficult. Nearly every teacher has experienced a multitude of complaints about the perceived difficulty of a physics course. The question remains: Is physics really that difficult? If we ask Merzyn: Yes, it is. (Merzyn, 2010)

So, why is it difficult? According to Merzyn’s article, one reason is the strong focus on mathematics and abstraction. At the same time, again according to Merzyn (2008), the amount of students interested in the real-world applications of physics is three times as great as the amount of students interested in the theoretical laws of natures. Currently, we use these findings to underline the importance of experiments. But we can use this findings also, like Redish (2004), to underline the importance of a more context-based education research.

At the same time, the use of authentic assessments to facilitate learning (Anderson, 1998) and to help students in achieving a better grade of scientific literacy (Chang, 2005) is strongly recommended. To make an authentic assessment, you need an authentic context but authentic assessments could also help the teachers to solve the problem of grading their students in such a learning environment.

Searching for an authentic context is not easy, because it has to be realistic or the students won’t accept it as such.
1.2.2 Intervention programs

For a successful intervention or any kind of opinion change, you have to convince your opposite. To do this successfully, various theoretical approaches have been formulated. We will discuss two approaches that, additionally, show exactly where we can use our scientific and rational reasoning and the teaching of reasoning to achieve the greatest gain.

One approach uses the rhetorical theories of Aristotle and his three modes of persuasion (Honeycutt, 2012). First, there is Ethos. It means the authority and credibility of the person who tries to convince someone. A medical doctor who speaks about cancer would be a good example. Then there is Pathos, the emotional appeal of a speech and its passionate delivery. And last there is Logos, which appeals to the rational mind. It works with facts and numbers to underline the importance of a subject.

The other approach stems from the Health-Belief-Model, developed in the 1950s by the U.S. Public Health Service (Turner, 2004). Originally, it tried to explain why people did not accept screening programs for tuberculosis. But it can be used today to explain in a broader context why people won’t quit smoking or get vaccinations.

There are four major variables, first the Perceived Seriousness: People have to see the discussed problem as serious or the implications as having an effect on their lives. Next there is the Perceived Susceptibility, which describes how likely it is in the subjective opinion that the target audience is confronted with the discussed problem. For example, if you go to the beach and have a light skin, you will use sunscreen to prevent skin cancer, because you perceive yourself as being susceptible. The third variable would be the Perceived Benefits. Using the example of sunscreen: People wouldn’t use it, if they didn’t believe it to be beneficial against skin cancer. In many things, people have to see or at least believe in a benefit of using a procedure or accepting a safety measure. The last variables are Perceived Barriers. This refers to the effort in time or money to change behaviour, but also to emotional barriers like fear of a test or embarrassment in front of peers.

If we just look at the aristotelic approach, we can easily see that physics could be used for the Logos part of an intervention program. Rational thinking and scientific methods of analysis fit very nicely in there. It is trickier to find a good spot in the Health-Belief-Model. But depending of the specific topic, you could use physics as a way to justify the Seriousness, to quantify the Susceptibility, to describe the Benefits or to dismantle the Barriers.

2. Implementation

2.1 Finding an authentic context: Crash Kurs NRW

Finding an authentic context for a physics course isn’t an easy task. Luckily, the police in the federal state North Rhine-Westphalia in Germany had an interesting idea to fight high numbers of accidental deaths of young drivers: Crash Kurs NRW. Originally it was developed in Staffordshire in England and consists of a stage show before a couple of hundred students in the age of 16 to 20 years.

In this stage show, various police officers, firemen and paramedics describe their personal experiences with severe accidents and the repercussions for all the involved peoples and families.

Figure 1. A Crash Kurs team during the final address (Bresges, 2011)
The goal is to foster road safety by describing how speeding, drugs, improper use of safety belts and using of cell phones can lead to serious or deadly injuries following a car crash.

Looking at this program from a theoretical view (1.2.2) we see a strong Ethos – real police officers and firemen – and a strong Pathos, the emotional distress of seeing accidents and hearing about them.

Yet, there is only limited opportunity to address the rational side of the problem. Also, in a stage show, one cannot address the subjective opinions about safe driving or help the students individually to understand the problem. So it became clear, that some educational follow-up program had to be devised.

Despite this limits, such a program can be a great authentic context for a physics course. Cars can be great examples for positive and negative accelerations; you can calculate velocities, energies and forces of impact, all with the very realistic example of a moving car. At the same time, this knowledge can help the students understand accidents.

Looking back at 1.2, the seriousness of accidents can be described in a very thorough way by the use of physics. The forces to which passengers are subjected can be exactly calculated and the results compared to e.g. jumping from a building. The benefits of safer driving can also be explained using physics.

There are a few more reasons why an educational follow-up program is needed for the Crash Kurs NRW. The stage shows are conducted in schools and school officials want an educational framework. Also, to better remember the messages from the stage show, repeating them in school is a good way to go. And lastly, because of the emotionally stimulating and psychologically demanding nature of the stage show, educational follow-up programs can have the beneficial side-effect of letting the students talk and calm down in a safe environment.

To summarize: The Crash Kurs NRW can be a good authentic context for physics education because of the many possibilities to use physics in the context of road traffic. At the same time an accompanying physics course can support Crash Kurs NRW in various ways, especially in the improvement of the Logos and in fulfilling the requirements of the health-belief-model.

2.2 Educational content of the follow-up program to Crash Kurs NRW

To fulfil its role as a good follow-up program, various modules were developed, for physics and other subjects. Any school can access all the modules over an ICT platform that is being hosted by the University of Cologne (www.crashkurs-nrw.uni-koeln.de, 2012).

2.2.1 Nonphysical content

At the moment, a few modules exist which can be used in nonphysical subjects.

First there is a role-play, named “Two Minutes before the crash”. In it, the students play various passengers of a car, which is about to crash in two minutes. The students use cards with role descriptions of the passengers and their connections with each other are. After their first crash, the students have to try and prevent it while still adhering to their role descriptions. Here the students can learn, how to surmount their perceived barriers (1.2.2).

In another module teachers create posters with their students about fast driving. The goal here is teach communication competencies and give them an opportunity to establish themselves as experts of the topic.

2.2.2 Physical content

The physical content consists of various modules, including a computer simulation of reaction time, work sheets and accident reports from the police.
The computer simulation is called “Mechanik und Verkehr - Mechanics and road traffic”. Here, the deceleration of two cars with different velocities is compared and visually displayed. The software has the format of a 3D simulation. The students have to react to an obstacle and the first - slower - car will come to a stand right before the obstacle. The second, faster car will inevitably hit the obstacle. The residual velocity, which is calculated according to the reaction time of the students in the first car and the correct physical formula for negative acceleration, is displayed and visualised by the deformation of the car. The students can then examine the data from the cars and see for themselves, why the second car hit the obstacle and how important the reaction time and the higher velocity is. So they can experience for themselves why speed limits are in place and what the consequences are if you ignore them. Most importantly, they can analyse this in a logical and scientific way.

The work sheets and handouts address the physical and mathematical causes of a possible accident by letting them calculate the velocities and energies of moving cars as well as the resulting forces if two cars collide. They have, for example, to calculate the distance which is crossed during the reaction time or the force on the arm of one passenger who is driving one of the in the accident involved cars. The goal here is to let the student’s reason about the causes of accidents without resorting to emotional arguments or being unsure about this causes. They have to use a calm and rational way of thinking.

Figure 2. The police sketch of an accident (www.crashkurs-nrw.uni-koeln.de, 2012)

The accident reports of the police are authentic reports with blacked out names. Here, the students have to use their physical knowledge gained in the aforementioned worksheets to determine which of the drivers is to which extent responsible for the accident and why it happened. Here they have to include different surface frictions in their reasoning to get a correct knowledge of the velocities of the involved cars. The goal here is to let them use their knowledge to solve a real case and to give the teacher an opportunity to see, which of his students should get more guidance in understanding the task and finishing it.
3. Evaluation of Crash Kurs NRW

3.1 Goals and design of the evaluation

To get a better understanding, how good the stage show and the educational follow-up program works, two evaluations were commissioned. The evaluation focused on two different stages of the development and implementation of Crash Kurs NRW.

Figure 3. Focus of the evaluations (Bresges, 2011)

The first evaluation was a process evaluation to examine the process of the development of the stage shows in the different police departments and the use of the educational modules in the involved schools in the pilot project. The second evaluation examined the impact of the stage show and the educational modules - at least the ones, which were used by the schools - on the students and their opinions about fast and safe driving.

The process evaluation had as goal to identify the best way to develop the stage show and the best way for the police to work with schools. Its second objective was to examine the utilization of the educational modules. This evaluation was done with the help of direct interviews and phone interviews with a prepared list of questions as well with an online survey for the teachers in the schools. The Evaluation was done by Prof. Dr. André Bresges of the University of Cologne (Bresges, 2011).

The impact evaluation had as goal the examination of the exact impact on the students, so it could later give important information for the improvement of the stage show and the educational modules. It was done in 14 schools with about 2000 students, with the help of a written survey at three different times, directly before the stage show, two weeks after it and 3-6 months after the stage show. It consisted of a quantitative evaluation by Dr. Markus Hackenfort of the ZHAW Zurich and a qualitative evaluation by Aleko Janssen of the University of Cologne.

3.2 Findings of the evaluation

At the moment, we can only talk about the process evaluation and the qualitative part of the impact evaluation. The quantitative part of the impact evaluation is not published at the moment.

3.2.1 Process evaluation

The focus of the process evaluation is mostly in the area of team building, team development and cooperation between the police and schools. The oral and written feedback of the involved teachers and their schools was generally positive (pg. 55, (Bresges, 2011)).
In the team building process, a few critical roles were found which emerged by trial-and-error in the various police teams. Especially important was the distinction between an organizational team leader and a creative team leader. The first should be responsible for contacting other organizations (e.g. hospitals and schools) and getting money for the team. The second one should be responsible for the content of the stage show, for example which accidents would be presented and how the lighting of the stage should be directed. Other team members should be given specific tasks according to their personal area of expertise, for example a hobby musician could be given responsibility for the musical score of the stage show. The further development of the team should include constant supervision, either from internal or external experts, to avoid traumatizing the team. Equally important is the constant care for the non-police speakers in the stage show. In most cases monetary compensation is not needed or it is even detrimental because of fiscal reasons. More important is a caring attitude and a good team spirit in the whole team. No deterioration of the quality of the stage show over repeated events was observed. At the contrary, the speakers seemed to know their own part better and showed less nervousness.

Very interesting was the feedback from schools and teachers. In the online survey they were full of admiration for the stage show and were very interested in the educational follow-up program. Most of the teachers used various parts of the program, coinciding with their subject of study. Contrary to these findings were the experiences of the police. For most of the time it was very difficult for the police to get into the schools or correctly conveying information about the stage show. This disparity can be explained by the low quantity of teachers who took the survey in comparison to the much greater quantity of teachers who were involved in the whole program.

**Figure 4.** Which modules from 2.2 were the most interesting for the teachers (Bresges, 2011)

As can be seen in Fig. 4, the most interesting modules were the regional accident (“Unfall regional”), a discussion between teachers and students (“Unterrichtsgespräch”) and a talk about how to prevent accidents (“Schutzmöglichkeiten”). On the left scale you can see the number of mentions, 32 teachers answered this particular survey.

The evaluation summarizes that it seems at the moment that there is a demand for further in-service training of the teachers regarding to the necessity and the possibilities of the educational follow-up program and perhaps a concentration on the more popular parts of the current program (pg. 56, Bresges, 2011).

3.2.2 Impact evaluation

As we cannot, at the moment, discuss the quantitative part, the findings here presented are from the master thesis of Aleko Janssen and his qualitative evaluation. His evaluation design was framed in such a way as to analyse the educational follow-up program.

He described an accident and asked two questions about it: “In your opinion, how could this accident happen?” and “How could the driver or the co-driver have prevented this accident?” (Janssen, 2011).
The students answered these questions together with the survey from M. Hackenfort, so he could compare the answers from before and after the stage show and its educational follow-up program. In the categorization of the answers, he found 8 (a.-h.) categories regarding the causes of accidents in the answers to the first question and 6 (e.) categories regarding the prevention of accidents in the answers to the second question. He then compared 50 students from different schools. One of the schools used the aforementioned educational follow-up program (2.2), the other school used an in-house program. To understand the figures, a short list of the derived categories is necessary, but restricted to the categories with big variations:

“In your opinion, how could this accident happen?”

Weather conditions
f. Seat belt
g. Alcohol or drugs

“How could the driver or the co-driver have prevented this accident?”
a. Do not enter the car
c. Do not get distracted
e. Use a seat belt
f. Act responsible as co-driver

The first three categories are answers to the first question, the second three from answers to the second question. In the figure are the categories aligned in the same way. The number is the difference between the number of answers in the individual categories at the first and third testing time (3.1).
Figure 5. Differences before and after Crash Kurs NRW at school 1 (Janssen, 2011)
Figure 6. Differences before and after Crash Kurs NRW at school 2 “(Janssen, 2011)”

Figure 5 shows the school with its own educational program, Figure 6 the school with the program from 2.2. As you can see and elaborated about by Janssen, the causes of accidents as seen by the students of school 1 get more realistic with their educational follow-up program (seat belt is never a cause for accidents, it is only relevant for the severity of the injuries). But the students at school 2 seem to know a lot more about how to prevent an accident and how they themselves could prevent such accidents.

Janssen summarizes, that the educational follow-up program in 2.2 is much better in giving the students knowledge about what they could do to prevent accidents. The biggest shortcoming is in his opinion, that “missing experience” (d.) is only seldom given as an answer, even if it is one of the most important causes for car accidents.
4. Conclusions and future development

4.1 Improvement opportunities

From the two aforementioned evaluations it seems, that two improvements can be implemented in the educational follow-up program.

First, the acceptance of teachers for the program has to be higher. This could be achieved by in-service training, where the teachers themselves would be the recipients of the stage show or the educational follow-up program. Many teachers spoke in conversations about the difficulty to find the time to correctly select follow-up modules or prepare them for their class. They also have to understand, why it is important for them to use the modules from 2.2. This too can be achieved by the in-service training, with the example of the schools in (Janssen, 2011).

Secondly it would be a good idea to improve the modules themselves to more accurately convey the causes of accidents and how to prevent them. According to the findings of A. Janssen, the modules already serve their basic functionality of providing knowledge to prevent accidents, so changes have to be done carefully.

4.2 Further development

The theoretical approach shows clearly that there should exist a rational part, an educational follow-up to the emotional stage show. This part should not be about the emotional consequences of unsafe driving, instead rational and scientific thinking should be the main content.

Combined with the findings of the evaluation, there should be a few guidelines for further developments:

- The students should experience the necessity of certain safety rules, like the ban on using cell phones, and should explore their own driving experience (3.2.2)
- The students have to understand, how big the risk they are taking really is (1.2.2)
- The students should train their competence as a co-driver more thoroughly and this should be a key issue of the follow-up program (1.3, 3.2.2)
- The follow-up program has to be easy to use and easy to implement in different kinds of schools and in different kinds of school subjects (2.2)
- The follow-up program has to be as authentic as possible to improve the mental associations of the students (1.2)

Fitting in these guidelines could be the following four-stage-design:

1) The students should experience car driving in a safe environment, where they can emulate the various distractions and explore their own capability. Where a real experience is impractical or impossible, driving games could be used. They could either be programmed for this application program or may be commercial games. Their realistic appearance would be beneficial for the immersion of the students.

2) The students should address the risks of road traffic by using physics to calculate the high impact energies and forces inherent in a driving car. They could use accurate computer simulations to understand, how exactly a car decelerates and how important reaction times are. Here they can also learn, how to rationally phrase arguments about fast driving.

3) To give the students the opportunity to learn about how to prevent accidents, a role-play, similar to the one in 2.2.1 can be used. Not limited to one iteration, various students could participate in such a role-play and then discuss the topic in moderated talk.
4) At last, the students have to use their knowledge in a real and authentic way. They can do this by analysing locations where more accidents than typical happen. These locations should be interesting enough so the students will feel challenged by the task. The task should be concluded with a short presentation either in front of the other students or in a bigger school presentation.

All the four parts would be made available to teachers freely and would consist of detailed instructions how to implement them and what alternatives exist to specific portions of the individual part. At the same time the teachers will be made aware which part fits best to which subject of study and that every part, maybe except the fourth one, could be left out.

4.3 Summary

In Summary, even if there are improvement opportunities and a few shortcomings, the feedback from teachers and schools as well as from police officials is very promising. With Crash Kurs NRW, it seems that a good authentic context was found, which provides the unique goal of not just being a context for physics, but helping students to accomplish something with their knowledge of physics. The question, “How can we make physics meaningful and interesting for the students without losing sight of the content of physics education?” can certainly be answered by the use of road traffic in general and especially Crash Kurs NRW.

And it isn’t a one-way-transfer either. The use of physics education greatly benefits Crash Kurs NRW, because it is the easiest way to give the students the much sought-after rational component, the Logos. So, with this context, we don’t just found a good authentic context, we did and we will do something beneficial for society in general.

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Realizing Authentic Inquiry Activities with ICT

André Heck, Universiteit van Amsterdam, The Netherlands, a.j.p.heck@uva.nl
Ton Ellermeijer, Centre for Microcomputer Application, The Netherlands, ton@cma-science.uva.nl

Abstract

We report on our research and development work in the last decade, which has recently been presented in a PhD thesis (Heck, 2012a) and which generally aimed at improving the contribution of ICT to inquiry-oriented mathematics and science education. We present the research setting and main outcomes of the PhD study, the scope of which was limited to pedagogical and software design perspectives on the use of ICT in quantitative mathematical modeling. We discuss how the study provided on the one hand a deeper understanding of the ways in which ICT can support students in carrying out an inquiry activity and can reduce the gap between research of students and professionals, and how it led on the other hand to more insight in what it takes to develop an integrated computer environment for mathematics and science education.

Introduction

We concur with Hodson (2009) that there are at least three major goals of mathematics, science and technology (MST) education: (1) learning MST, by which we mean the familiarity and understanding of ideas and concepts inherent in these fields; (2) learning about MST, which adopts a much broader view of MST, focusing on the philosophy, history and methodology of these fields; and (3) learning to do MST, by which we mean that the learner gains the ability to engage in and develop expertise in scientific inquiry and problem solving. Our focus was (and still is) on providing students with opportunities to experience how science is enacted, i.e., with authentic science, and in particular on providing students with ICT tools that allow them to act as ‘real’ scientists. This is how we mainly interpret the authentic nature of practical work of students: Activities in which students do research in much the same way scientists and practitioners do and in which they use high-quality tools that are similar to professional tools, but that have been designed for educational purposes. The intention to approach MST education as a study of scientific practice is more easily stated than implemented in a nationwide MST curriculum. Luckily, the Dutch curriculum reforms of the last two decades in upper level secondary education offer opportunities: Students must build up a portfolio consisting of small practical investigation tasks (4-10 hrs) and one rather large (80 hrs) cross-disciplinary research or design experiment in order to record the progress in their learning of doing science.

Our research activities were mainly exploratory case studies on the student performance and the usability of developed tools in ICT-supported practical investigation tasks in class and in out-of-school research projects. In most of these studies and field experiments, pre-university students carried out quantitative mathematical modeling activities, i.e., they explored mathematical models based on science principles, with the support of ICT tools in order to come to grips with natural phenomena and to interpret real data. By real data we mean data collected by students in experiments and secondary data originating from professional empirical research. Students used in their practical work the hard- and software environment Coach (Heck, Kędzierska, & Ellermeijer, 2009). In many activities, students could apply ICT for doing research in a way that resembles research by scientists and practitioners. The students’ inquiry activities were amongst others about human locomotion (walking, skipping, running, ...) and other subjects in movement science, sports science, quantitative pharmacokinetics, and analysis of digital images and video clips. In the PhD thesis (Heck, 2012a), brief overviews of ten classroom studies and of twenty field experiments and student research projects have been presented; more detailed accounts have been published in scientific journals, teachers’ journals, and conference proceedings. In this paper, work on modeling bouncing gaits is used to exemplify the kind of student activities that we developed and evaluated in a research setting. We present the aims and set-up of the study, and we report on the main outcomes.
Research Setting and Methods

Driving questions in our R&D work were (and still are):

1. How can the use of ICT and in particular of an integrated computer learning environment contribute to the realization of challenging, cross-disciplinary practical work of good quality, in which pre-university students can work with real data, apply mathematical methods and techniques in concrete problem situations, improve their mathematical and scientific knowledge and skills, and increase their mathematical and scientific literacy?

2. What integrated tools should the computer learning environment provide for inquiry-oriented mathematics and science education? What are the requirements for the computer learning environment from a mathematical point of view and do they link up with requirements coming from science fields?

In other words, we aimed at (1) better understanding of how, why, and to what extent ICT tools can support students in their learning and practice of scientific inquiry; and (2) more insight in what it takes to develop an integrated computer environment for learning mathematics and science in the context of inquiry-oriented approach, the usability of which is explored within educational practice. Hence, research and development are intertwined. Focus was on students’ working with real data and on the design of supportive ICT tools.

The framework for our research and development work was formed by elements of design research (Van den Akker, et al., 2006), case-based design of educational software (Kahn, 2008), frameworks on using multiple representations (Kaput, 1994; Ainsworth, 2008), frameworks on evaluating inquiry activities of students (Gott & Duggan, 1995), and of models of mathematical modeling (Blum, et al., 2007). Looking at design research aspects of our study, it can be characterized as type I design research in the typology of Richey and Nelson (1996): “The product development process used in a particular situation is described and analyzed, and the final product is evaluated.” Within the distinction made by Van den Akker (1999, p. 6) between formative and reconstructive studies, the research work belonged to the first category.

From design research we took the perspective that it involves design of an intervention or experiment in the real world, that the output of my research must have practical value to real world users, and that teachers are involved in the research. We carried out three types of case studies:

1. classroom research studies, in which students did practical investigations on the basis of specially designed instructional materials;

2. field experiments, in which ICT innovations were tried out on a small scale and not necessarily in the classroom;

3. usability studies, in which we evaluated the potential of a specific ICT tool or a set of integrated tools in a particular subject or domain, leading to a set of sample activities.

These exploratory case studies served many goals:

- They were meant to gain insight in the needs of secondary school students for doing authentic inquiry work.

- They helped specify requirements for an integrated computer learning environment from a mathematical point of view.

- They served to test the usability and scope of (prototypical) implementations of particular tools for collecting, processing, and analyzing data.

- They gave an impression of the potential of ICT regarding the realization of practical work in which secondary school students are engaged in activities such as experimenting, data collection, and data analysis in much the same way as scientists and practitioners.
We took the iterative process of design research, which includes cycles of innovation and revision. But instead of the common cyclic approach to design and exploration of new teaching and learning routes, we let the case studies be the cycles in our design research as illustrated in Figure 1.

Figure 1. The set-up of the study from a design research point of view.

Classical methods for data collection in design research were applied in the classroom case studies: participatory classroom observation, teacher interviews, questionnaires for students, audio and video recordings of teacher instructions and group discussions of student teams, computer registration of student activities, and collection of worksheets and reports of students.

Tool development also had a cyclic structure, which typically went through phases of planning, development, testing, and release. This spiral model of prototype development, evaluation, and improvement resembled the following user-centered design activities taken from the ISO 9421-210 (2010) standard:

1. understand and specify the context of use;
2. specify the user and organizational requirements;
3. produce design solutions to meet user requirements (typically in the form of prototypes);
4. evaluate the designs against requirements.

When these human-centered design activities are applied to design of education software and when emphasis is put on the understanding and specification of the users, the activities and the context of use, and on the evaluation of the design by case studies in the envisioned context of use, then one speaks of a case-based design of educational software (Khan, 2008). The case-based design process can be split into three parts identified as planning, development, and testing part of the design process. Kahn (2008) linked the following five sequential phases of the design process into these parts:

1. studying pedagogical theory in preparation for the next phase;
2. making a conceptual design of the educational software;
3. constructing the program architecture;
4. developing a prototype;
5. testing of the prototype.

We adopted this framework for developing educational hard- and software. As shown in Figure 2, taken from Kahn (2008, p. 427), case studies inform phase 2 and 4, and teacher feedback informs phase 2, 4, and 5. The use of this framework for the (re)design of video analysis tool, the data processing and analysis tools, and the graphical system-dynamics modeling tool of Coach 6 are discussed in detail in the thesis.
These tools are in fact part of a versatile toolkit. The theoretical rationale of tool integration is that the use of multiple external representations is crucial for deep understanding of real phenomena and that this process of understanding is promoted when learners are not distracted by technical burdens that could have been avoided by the provision of tools that work well together.

Figure 2. Phases of a case-based design process of educational software.

The Design and Analysis Framework of Student Activities

We structured and analyzed many of the quantitative mathematical modeling activities in the case studies on the basis of a modeling cycle of Blum and Leiß (2005) combined with a classical empirical inquiry cycle. The single framework, shown in Figure 3, resembles the modeling-experimental bi-cycle of Fuchs (2008) as a visual model for a form of the Scientific Method. We also used this framework for elaborating our view on quantitative mathematical modeling competency. It must be kept in mind that in reality the two cycles are not as disjoint as suggested: One can go in any order through both cycles. One can even switch halfway the theoretical modeling cycle, when a mathematical model has been derived, to an experimental cycle to verify whether the model is promising.

Figure 3. A Framework of quantitative mathematical model.

Overview of a Sample Investigation: Modeling Bouncing Gaits

Mathematical modeling often goes as follows: first one simplifies the situation to such an extent that a simple model can be constructed. Hereafter one evaluates this model, preferably by comparing it with experimental data, and one adapts it if necessary. In the process of evaluation, parameter estimation plays
an important role, too. The complexity of finding suitable parameter values must not be underestimated. Adaptation of the model normally means that one makes the model more complicated by taking more factors that cannot really be neglected into account or by undoing some earlier simplifications. One comes into the process of simplifying first and then adding step-by-step more details to the model, with the purpose of matching the model better with reality. It is our belief that by looking at various models of one and the same phenomenon a critical attitude of students is promoted.

An example of this progressive modeling approach is presented here: modeling bouncing gaits of humans such as bouncing on a jumping stick, hopping, and making kangaroo jumps. This case study, in which human body motions were explored through video analysis and computer modeling, also serves the purpose of exemplifying the kind of inquiry activities that we developed for pre-university students. Details can be found in (Heck & Uylings, 2011); here we only sketch how mathematical models using basic biomechanical principles were explored and assessed with the help of experimental data obtained from video measurement. It concerns three motions:

1. Vertical bouncing on a jumping stick;
2. Hopping upward;
3. Hopping forward like a kangaroo.

Highlight was that the model of a planar inverted spring-mass system worked qualitatively and quantitatively well for the complex motions of hopping, skipping, and running at moderate speeds, i.e., in bouncing gaits. These examples of video analysis and modeling activities give a good impression of the potential of the subject of human gait for student practical investigations or projects and as a context for applied mathematics and physics at secondary and undergraduate level. They also illustrate how close one can get to contemporary biomechanical research (cf., Geyer, 2005).

The planar inverted spring-mass system was introduced in the 2008 nationwide secondary physics computer-based examination for pre-university students. The subject was video analysis and modeling of vertical bouncing on a pneumatic jumping stick. The rather clear situation of a periodic motion of a person on a jumping stick can be described well with a model based on simple mathematics and physics: In the aerial phase, only gravity is assumed to play a role in the motion, and during ground contact Hooke’s Law of elasticity is applied to the spring deformation. Then, the dynamics of the spring-mass system is determined by a second order differential equation and two initial conditions. The dynamic system can be exactly solved, but also be numerically solved via a graphical, system dynamics-based modeling tool. The left-hand window in Figure 4 shows a graphical model in Coach 6 that numerically solves the system of equations.

![Figure 4](image)

Figure 4. A graphical model implementing the one-dimensional spring-mass model and the results of a simulation run compared with data obtained from a video analysis of a video clip.

The diagram in the middle shows the graph of the computed height and the point plot of the vertical heights measured in a digital video recorded while the student was vertically bouncing on his jumping stick. Simulation results match well with the measured data for suitable parameter values. The measured data suggest that a sinusoidal regression curve would also describe the data quite well, and indeed it does from mathematical point of view. But the spring-mass model is considered better than the experimental modeling via regression because it is based on physics laws. According to this model, a sinusoidal
displacement during contact phase is followed by a parabolic aerial phase. This kind of judgment of the quality of a model is what students should learn.

It turns out that the one-dimensional spring-mass model is also a good model for human hopping upward without the support of any device. For the purpose of data collection, students went to the Sports Center of the University of Amsterdam in order to hop upward and forward on a stationary and operational motorized treadmill, respectively. Motions were recorded with a high speed camera at a speed of 300 frames per second so that as many details as needed could be observed and a rather high time resolution was assured (See Figure 5).

Figure 5. Video analysis of an upward hopping girl on a motorized treadmill that is not turned on.

Under the assumption that only gravitational force and spring force play a role, Newton’s second law of motion and Hooke’s law of elasticity lead to exactly soluble equations of motion for the height during contact and aerial phase. In the right-hand side of Figure 5, a best sinusoidal function fit for the contact phase is visible. By means of analytical solutions of the system of differential equations, initial values of parameters in the model were determined from more easily measurable quantities and then subsequently improved by regression methods or via computer modeling. As shown in Figure 6, the graphical computer model in Coach 6 can be extended to include the expressions for gravitational energy (with respect to the height taken equal to the spring-leg length), the spring energy, the kinetic energy of the system, and the total energy of the system. A student can then diagrammatically explore the different forms of energy during the motion and examine that conservation of energy holds for the model system. An animation can be used to investigate the effect of parameters.

Figure 6. A Screen shot of a Coach activity consisting of a computer model and an animation of a vertical spring-mass system, in which measured hip heights are compared with computed results and energies are computed to examine forms of energy and the law of conservation of energy.
What sets the seal on the work is the application of a planar inverted spring-mass model to human double-legged forward hopping, that is, to a motion resembling kangaroo jumping. The model is now two-dimensional. In comparison with the one-dimensional spring-mass model of upward hopping, we have two new conditions: the leg angle of attack $\alpha$, when the leg makes ground contact, and the angle of take-off velocity $\beta$, when the leg loses ground contact (see Figure 7). Note that $\tan \alpha = -y(0)/x(0)$ and $\tan \beta = v/u$, where $u$ is the horizontal landing speed (equal to the speed of the motorized treadmill when the gait happens on such device) and $-v$ is the vertical landing and take-off speed.

Figure 7. The planar inverted spring-mass model for forward hopping and running.

The fact that the motion is now in two dimensions makes the modeling, both from mathematical and computational point of view, much more difficult and only doable for students with a keen interest and good ability in mathematics and physics. For less gifted students the one-dimensional inverted spring-mass model is already challenging enough. To give an idea of the complexity of the two-dimensional case we mention that, in order to implement the equations of motion in a graphical modeling tool, a solution for moving the coordinate system from one stance point to the other must be found. The fact that the modeling tool of Coach 6 is designed as a hybrid system that combines a classical system dynamics approach with event-based modeling for processes that change abruptly helps solve the implementation problem of a moving frame. Nevertheless, the computer model shown in Figure 8 looks frightful and incomprehensible. This is compensated by the awesome comparison of model results with experimental data, visible in the lower-right corner of the screen shot.

Figure 8. Screen shot of a simulation of the planar inverted spring-mass model of forward hopping like a kangaroo.
Main Outcomes of the R&D Work

What lessons did we learn from developing ICT tools that are integrated in an open, activity-based, multimedia authoring environment for MST education and from exploring their usability in specific practical investigations for upper secondary students, in sample activities, and in usability studies? What answers can we give to the two driving questions listed before? Below, we lift the veil.

Regarding the first question about realizing authentic practical work via ICT, the main role of ICT in investigative work can be summarized as the change of the computer into an instrument that allows students to collect real-time data of good quality, to construct and use computer models of dynamic systems in much the same way as scientists, engineers, and practitioners do, and to compare results from experiments, models, and theory. Furthermore, students can develop and practice through the activities their research abilities. The fact that they must apply their knowledge of mathematics and science in a meaningful way in a concrete context (hopefully) leads at the same time to deepening and consolidation of this knowledge. As a bonus, ICT can bring the real world into mathematics and science education in an attractive way.

The case studies showed that ICT tools help bridge the gap between school science on the one side and the real-world application on the other side. Especially, the motion analysis studies illustrated that upper-level pre-university students, when supported by a suitable versatile computer environment, can work directly with high-quality, real-time data about human body motion in much the same way movement scientists do. In such inquiry activities, students can practice mathematical knowledge and skills such as graph comprehension, numerical differentiation and integration, data processing and analysis, regression, and so forth. Understanding, interpretation, evaluation, and manipulation of data by means of ICT plays a large role in such activities and we found that the participants in the case studies performed surprisingly well (or at least better than expected). In the practical investigations, student can also develop the critical attitude that is necessary for successful modeling of natural phenomena. For this it is very important that the students can compare the results of computer models with real data, preferably collected in an earlier measurement activity. Confrontation of a model with reality turns modeling not only into a fun way of learning, but it also makes it exciting, challenging, and concrete work. Students all seemed to be attracted by this kind of practical work. It turned out that, as continuing work, some of them could autonomously do interesting research projects, obtain results of good quality that were comparable with results published in scientific or professional journals, and get a publication out of their work (e.g., Heck & Van Dongen, 2008; Heck, Knobbe, Nijdam, et al, 2011). Anyway, we experienced with regards to motion analysis that:

- most participants in the classroom case studies were sufficiently able to carry out sub-processes of quantitative mathematical modeling on request;
- not only upper-level pre-university students, but also students in pre-vocational secondary education were able to get an impression of what it takes to do scientific inquiry and to develop inquiry abilities by carrying out a small investigation task at their own educational level using digital video technology.
- the radius of action of video analysis, that is, the range of situations in which a person is able to activate his or her video analysis competency, seems large. Students who learned and practiced video analysis in one situation (e.g., gait analysis) seemed to have no difficulty in applying it in other situations.

The surprisingly quick uptake of video analysis technology and motion analysis by secondary school students does not mean that there were no comments on the quality of the students’ work and on the support level of the ICT tools, but at least there were no insuperable obstacles or quality issues that are difficult to improve.

Regarding the second question about a proper set of integrated tools in a computer working environment for inquiry-oriented mathematics and science education, one of the main outcomes was the progress made in the realization of the renewed STOLE concept in a particular computer environment, in our case in Coach 6 (Heck, A., Kędzierska, E. & Ellermeijer, T., 2009). STOLE is an acronym for Scientific and...
Technical Open Learning Environment (Ellermeijer, 1988). Originally, it was a vision of a hard- and software environment in which tools for measuring, data processing, and modeling are integrated in a single system that supports students’ learning in an inquiry-based approach of science education. Later, in the nineties, a new vision on practical work in science education arose that promoted practical investigations and research projects in which students would be engaged in activities that resemble those of scientists and practitioners (cf., Gott & Duggan, 1995; Wellington, 1998; Woolnough, 2000). The changed technological and pedagogical circumstances asked for a renewal of the STOLE concept, especially for the design phase of student-directed practical work and research projects. In this phase, a student researcher needs information: (s)he must analyze the scientific problem, simulate a model, or look up information about work of others. Thus, the computer is considered more than only a tool to collect, process, and analyze data. It must also give access to information resources and allow the display of information in various formats. The display of information and the inquiry nature of students’ activities ask for multiple linked representations in multimedia-based activities. It was also envisioned that it should be possible to fine-tune the whole cycle of doing investigations and design work. This means that a teacher should be able to design a sequence of activities for a particular investigation, and to organize these activities in a project to structure the instructional materials (experiments) for the students.

This renewed STOLE concept was first implemented in Coach Junior, released in 1998. This marked the start of the PhD study and since then the quality of data processing and data analysis has been improved, more tools for video capture and measurement on digital images and video clips have been incorporated (also due to rapid advancement of ubiquitous technology at consumer level), authoring of activities and the structural organization of activities have been upgraded, and new modeling tools like graphical modeling and computer animations have been developed, amongst many other things. Highlights of the digital image and video analysis were: video capture with webcams and high speed cameras, video editing, automated point tracking, correction of perspective distortion, digital image analysis, and simultaneous video recording, sensor-based measurement, and control of experiments by sort programs. New elements of computer-based modeling, simulation, and animation were: numerical algorithms, graphical system dynamics-based modeling, an extension toward easy event-based modeling, an extension of graphical modeling with a process icon [needed, for example, in modeling chemical kinetics graphically (Heck, 2012b)], and model-based animation. Data handling was redesigned by improvements of tools for data smoothing, numerical differentiation, regression analysis, and signal analysis.

All outcomes discussed so far were positive. Although this holds in general, it’s not all roses there. There are many, small and large, comments to be made on both student competency and tool design. We mention some of our findings that call for further research and field work to improve MST education. Much more can be read about this in the thesis (Heck, 2012a).

Developers of a versatile computer learning environment that offers integrated tools for mathematics, science and technology are faced with the following two difficult questions: How to deal with

1. the versatility of mathematical language and mathematical notation, and in particular, how to deal with the variability of the concept of variable in mathematics and science?

2. the differences in language between mathematics and science?

The multimedia authoring of student activities helps instructors and designers of instructional materials to make their own choices. However, the two questions remain puzzling. The interested reader is referred to (Heck, 2001; Ellermeijer & Heck, 2002) for a thorough discussion of these issues.

The students who participated in the case studies had difficulties at all levels of graph comprehension in the framework of Curcio (1987) and Shaughnessy (2007), except the first level of reading the data. At the level of reading between and beyond data, students had difficulties in interpreting and reasoning with unfamiliar graphs and graphs of derived quantities in terms of the real-world context from which the graphs originated. In video analysis activities, many a student did not autonomously use the video scrubbing technique to link graph features with motion events, as if they had forgotten about this feature of the computer learning environment. Reading behind data was difficult, but not unreachable for pre-university students.
Spreadsheet-based case studies about survival analysis and data handling of weather data illustrated this. In cases where it is less obvious that a global trend and a superimposed function can be separated, students seemed to neglect the possibility of a regression model consisting of a sum of mathematical functions. We also noted in some classroom case studies that students tended to stick to a global view in data fitting and did not autonomously consider the idea of taking a component-wise view in data fitting.

In the case studies it was often observed in class and noticed in students’ written reports that the students had rather weak algebraic skills and lacked confidence in using mathematical formulas. We had the strong impression that the so-called algebraic expectation (Pierce & Stacey, 2004) of the students, which is the thinking that allows a student to monitor working with mathematical formulas, was underdeveloped, hindered them in their work, and led in some cases to a behavior of guessing a formula without giving it much thought. We also could not close our eyes for students’ difficulties associated with using multiple representations. The cognitive load is definitely enlarged when multiple representations come into play and it has been reported in many research studies (cf., Ainsworth, 2008) that students find retrieving information from representations, moving between and within representations, and coming up with appropriate representations difficult. The students who participated in the classroom case studies were no exception. Lack of graph sense and representational fluency (meaning, the ability to interpret and construct various disciplinary representations, and the skills to move between representations appropriately) seemed to hinder students in extracting all information that was intrinsically available in several linked representations and in evaluating the quality of their experimental work. Yet, it is important that students learn to work effectively with multiple representations. The underlying ideas of having multiple, dynamically linked representations available in the computer learning environment for inquiry-oriented MST education are not only that it reflects scientific practice, but also that

- it illuminates the meaning of actions in one representation by exhibiting their consequences in another representation;
- the number of ways to come to a solution of a problem increases;
- understanding of a phenomenon, a problem, or a concept is refined the more representations one can interact with;
- it supports the construction of deeper understanding when students relate those representations to identify strengths and weaknesses of particular representations and shared invariant features of all representations in use.

**Conclusions**

The presented research and development was about the role of ICT in secondary mathematics and science education. In many school projects, students could apply ICT for doing research in a way that resembles research by scientists and practitioners. This has resulted in better understanding of the ways in which ICT can support students in carrying out a research project. In addition, more insight was obtained in what it takes to further develop an integrated computer environment for mathematics and science education. The students used in their research the software and hardware environment Coach (Heck, Kędzierska, & Ellermeijer, 2009). The student projects were amongst others about human locomotion (walking, skipping, running, ...) and other subjects in movement science, quantitative pharmacokinetics, and analysis of digital images and video clips. It turned out that students could autonomously do interesting research and obtain results of good quality that are comparable with results published in scientific or professional journals. Figure 9, taken from a publication in a journal for physics teachers co-authored by a secondary school student (Heck & van Dongen, 2008), shows an experimental setting in which Coach has been used to do simultaneously a video recording, a sensor-based measurement of muscle activity via the surface EMG method, and data processing. It illustrates that ICT can help can bridge the gap between school science and real science.
Figure 9. Screen shot of a simultaneous video recording and measurement of the EMG signal of the gastrocnemius for normal walking, followed by data processing.

It is clear that research and development never stops. An obvious continuation of the presented work is educational research on learning trajectories for introducing quantitative mathematical modeling at secondary school level. ICT tools undergo continuous improvement and extension: For example, modern computer vision techniques could be incorporated in the current educational video analysis tools.

References


Students’ Conceptions about Radiation –
Selected Results from an Interview Study with 9th-Graders

Susanne Neumann, University of Vienna, Austrian Educational Competence Centre Physics
Martin Hopf, University of Vienna, Austrian Educational Competence Centre Physics

Abstract

Students’ conceptions have been and continue to be a major issue in physics education research. For the topic radiation, however, only a few studies about students’ conceptions can be found. As a consequence, our explorative study aimed to investigate associations and ideas that students have regarding radiation. We used semi-structured interviews to examine the perceptions of 50 high school students. The students were 14 to 16 years old and were randomly chosen from 7 different high schools in an urban area in Austria. Following an interview guideline, students were asked about their general associations with the term radiation as well as about their general understanding of different types of radiation. The interviews were recorded and partially transcribed. The analysis of the interviews revealed that the students’ associations were, to a great extent, very different from the scientific use of the term. The majority of the interviewed students associated the term radiation exclusively with nuclear radiation and also described the feelings that came up as mostly negative. Some frequent conceptions about radiation found in our study included the idea that radiation is always artificial and should be avoided by any means. Hardly any of the students knew that light is also a type of radiation. Furthermore, very few students seemed to be familiar with the concept of thermal radiation: The idea that all objects emit radiation seemed to be implausible to the vast majority of students. Based on our results, we would suggest that teachers should be aware of the narrow use of the term radiation in everyday language and should attempt to broaden their students’ conceptions by frequently talking about natural occurrences of different kinds of radiation. Also, they should not forget to discuss positive aspects of radiation such as light, thermal radiation and applications in medicine and technology.

Introduction

Our talk presenting students’ conceptions about radiation was based on our recent paper “Students’ Conceptions about ‘Radiation’ - Results from an Explorative Interview Study of 9th Grade Students” published in the Journal of Science Education and Technology. The present paper presents a rough summary of our study. For more details, we would like to draw the reader’s attention to the mentioned publication (Neumann & Hopf, 2012b).

The ideas that students bring into the physics classroom are considered to be of high importance for their learning results when following a constructivistic approach. The ongoing discussion about empirical research results and the theoretical framework of students’ conceptions are described in detail by Duit, Treagust and Widodo (2008). A lot of research results have already been accumulated in the field of students’ conceptions about various topics. The bibliography STCSE compiled by Duit (2009) gives a good impression of the abundant studies in numerous fields such as mechanics, electrodynamics, and optics. In the area of the topic radiation, however, very few studies exist about students’ conceptions. The majority of those studies investigated students’ conceptions about nuclear radiation and date back to the 1990s. Boyes and Stanisstreet (1994), for example, used questionnaires (n = 1365) and interviews (n = 60) to find out about students’ conceptions about radiation. Their results showed that students confused the dissipation of radioactive sources with the process itself, an idea that had already been discovered by Riesch and Westphal (1975). Boyes and Stanisstreet also found that students ascribed the effects of ionizing radiation to other environmental issues like the ozone layer and the greenhouse effect. Several studies investigating students’ conceptions about nuclear radiation were done by the workgroups of Eijkelhof and Millar (Eijkelhof, Klaassen, Lijnse, & Scholte, 1990; Millar & Jarnail Singh, 1996; Millar, Klaassen, & Eijkelhof, 1990), who found that students could not clearly distinguish between the terms ‘irradiation’ and ‘contamination’. They also traced back some of the misconceptions to unclear media reports by analyzing media releases in detail.
As there are very few studies that focus on other types of radiation (such as Libarkin, Asghar, Crockett, & Sadler, 2011) or the term radiation in general, we decided to investigate associations and ideas that students have regarding the term radiation. A first attempt to find out about younger children’s (9 - 12 years old) associations with the term radiation can be seen in our studies using the method of children’s drawings. We asked children to create drawings related to this term and we analyzed the motifs that were shown in their drawings. The results revealed that the older the students were, the more often they drew sources of invisible radiation (e.g. nuclear power plants, mobile phones). The younger kids usually restricted themselves to motifs like the Sun or light bulbs. A detailed analysis of this study can be found in Neumann & Hopf (2012a).

In order to find out about the ideas of older students, we decided to start an interview study. Another motivating factor for this interview study was that we assumed that the conceptions that students have in this field of science might have changed over the last decades because due to the fact that students of today are confronted with the term radiation in a lot of contexts (e.g. mobile phones, tanning booths, etc.).

This is why we posed the following research questions as a basis for our interview study:

• What do Austrian students at the end of their compulsory education associate with the term ‘radiation’?
• What conceptions do these students have about certain types of radiation?
• Which conceptions discovered in previous studies are still prevalent, which new conceptions can be found?

**Method and Data**

Our interview study comprised 50 semi-structured interviews (each lasting 10-15 minutes). The interview guideline consisted of open and closed questions and can be found in full in the above-mentioned publication (Neumann & Hopf, 2012b). To give a rough overview of the questions, we would like to list those questions that are closely related to the results that we are going to present. These questions include:

• What words come to your mind when you hear the word radiation?
• What feelings and emotions come up when you hear the word radiation?
• I am going to show you pictures of different objects. Which of these objects do you associate with the term radiation? Why?
• I am going to list some specific types of radiation. Please tell me whether or not you have heard of them, in what context you have heard of them, and if you think these types of radiation are harmful. Can they be detected by the human eye?
• You read in a magazine that all objects emit radiation. Do you think this could be true? Why (not)?

The 50 students (29 male and 21 female) who took part in the interviews attended 9th grade which, in Austria, is the last year of compulsory education. The students were 14 to 16 years old and we tried to include different types of schools (vocational and academic) with different socio-cultural backgrounds in order to allow for a great variance of backgrounds. The interviews were recorded, partially transcribed, and analyzed using peer-validated categories and content analysis. For the qualitative content analysis we used the method described by Flick (2009) and Mayring (2010).
**Selected Results**

**What do students spontaneously associate with the term radiation?**

As a first question, we asked the students to list words that spontaneously come to their mind when confronted with the term radiation. The majority of the students listed words related to nuclear radiation and the Sun. Also, UV radiation and mobile phones were frequently listed (see table 1).

<table>
<thead>
<tr>
<th>How many students listed terms in the context of …</th>
<th>…exclusively?</th>
<th>…along with terms of other categories?</th>
<th>…in total?</th>
</tr>
</thead>
<tbody>
<tr>
<td>… nuclear radiation…</td>
<td>20%</td>
<td>36%</td>
<td>56%</td>
</tr>
<tr>
<td>… the Sun…</td>
<td>14%</td>
<td>40%</td>
<td>54%</td>
</tr>
<tr>
<td>… UV…</td>
<td>4%</td>
<td>24%</td>
<td>28%</td>
</tr>
<tr>
<td>… mobile phones…</td>
<td>4%</td>
<td>20%</td>
<td>24%</td>
</tr>
</tbody>
</table>

**What kind of emotions regarding the term radiation come to the students’ minds?**

Subsequently, the students were asked what feelings come up when they hear the word radiation. More than half (52%) of the students stated that their feelings were mostly negative, only 16% said that they associated mainly positive feelings with the term. For each of the categories (“negative”, “positive” and “both negative and positive”), we would like to present one quote from the interviews in order to illustrate the categorization of the answers.

“Well, rather negative, because I think of nuclear radiation and … I don’t like nuclear power.” (I 43)

“Kind of positive because I associate the Sun and heat with it.” (I 2)

“Hmm… as far as health is concerned it’s rather bad, but apart from that… But you can also reach a lot with it. For instance, when you go and have an X-ray done, then you know what’s wrong with you… for instance… or the Sun, that’s something good, right?” (I 31)

**What are typical students’ conceptions about radiation?**

The major part of the interviews consisted mostly of open questioning. The students were shown several cards with drawings representing different objects in close connection to the term radiation (e.g. a tanning booth, a mobile phone, a laser pointer, an X-ray, …) as well as objects for which the connection is not as evident (e.g. a plant, a dog, a human being). They were then asked to talk openly about whether or not they think that these objects were related to the term radiation and why. The statements of the interviewed students were then analyzed and scoured for the most prevalent students’ conceptions, some of which we are going to present here:

- Radiation is always invisible. Light is different than radiation.
- Radiation is something artificial. Without mankind and technology, there would be less radiation around.
- All electrical devices emit harmful radiation.
- Radiation is bad for our environment. Factories, for example, emit harmful radiation through their chimneys.
- X-rays are not dangerous because doctors use them.
- Radiation is emitted by living creatures and helps us detect feelings.

For details on these students’ conceptions, we would like to refer to our published article (Neumann & Hopf, 2012b).
Which types of (electromagnetic) radiation have students already heard of?

We then asked the students to comment on different types of radiation. We wanted to investigate which types they had already heard of and whether or not they thought this type is visible to the human eye. Also, we asked how the students rated the risk potential of these different types of radiation. In Fig. 1 we present the students’ answers regarding the recognition of different types of radiation. For most types of radiation that we included, the rate of recognition was rather high (about 90%). The results, however, also show that about 40% of the students were not familiar with the term visible radiation. Also, most of the students who said that they were familiar with the term associated it exclusively with light coming from lasers and not with other natural or artificial light sources.

![Which Types of Radiation Have Students Already Heard of?](image)

**Figure 1.** Types of Radiation

Which types of (electromagnetic) radiation do students rate as potentially harmful?

Fig. 2 gives you an overview of whether the students that we interviewed considered various types of radiation to be harmful or harmless. With nuclear radiation, the results were very clear: Nearly all of the students stated that they consider nuclear radiation to be harmful, irrespective of the dose. X-rays, however, were perceived completely differently by the students. More than a third (36%) rated X-rays as harmless, usually stating that something which is used in medicine cannot, under any circumstances, be harmful. Out of all of the different types of radiation examined, infrared was rated as a quite harmless type of radiation. Nearly 75% of the students stated that it is harmless.
More results from our interview study can be found in our published article (Neumann & Hopf, 2012b). The publication includes results from questions like:

- what students associate with UV and IR,
- whether or not students think that UV and IR are visible to the human eye,
- whether or not the concept of thermal radiation is plausible for them.

**Discussion and Conclusions**

Our study has not only uncovered new students’ conceptions that had not yet been examined but it has also confirmed some findings from previous studies. Parallels can be found comparing our results to the study done by Boyes and Stanisstreet (1994). In both studies, students associated the term radiation mainly with nuclear radiation and argued that radioactivity is responsible for environmental problems. In our study, the Sun was listed as one of the major sources of radiation. This is consistent with our previous study (Neumann & Hopf, 2012a) where we used children’s drawing to elicit their associations about radiation. In both studies, the number of students who associated the Sun with the term radiation was quite large. We assume that this effect is a linguistic phenomenon. In the German language, the term Strahlung (= radiation) is very closely related to the Sun, whereas the English term radiation is not used in everyday language when talking about sunlight. For parallels found between our study and other studies that have examined UV and IR radiation, we would like to refer to our published article (Neumann & Hopf, 2012b).

Our results also show how closely connected students’ conceptions and their associations are. Students who associated infrared lamps (which also emit red, visible light) with the term infrared, for instance, usually stated that infrared radiation is visible to the human eye. Students who associated remote controls or the transfer signals of their mobile phones, with the term infrared, however, usually stated the opposite.
A similar result can be shown for UV radiation. The risk perception also seems to be dependent on the students’ associations. X-rays were typically associated with health care and therefore rated harmless. Nuclear radiation, however, tended to be associated with accidents in nuclear power plants like Chernobyl and was therefore rated harmful.

In this last section, we would like to suggest some implications for teaching. In agreement with science education research, we strongly believe that being aware of students’ ideas and taking them into account is a powerful tool for improving students’ learning.

Following our research results, we urge teachers to bear in mind that the term radiation has a limited meaning in everyday language. Taking that into consideration, it does not seem astonishing to see how many students exclusively associated nuclear radiation with this term. Regarding the broad use of the word radiation in science that includes such different topics like infrared radiation, light and nuclear radiation, it seems important for teachers to discuss this difference in meaning when introducing the scientific concept of radiation.

A lot of the students interviewed stated that they perceive radiation as something artificial. When teachers become aware of this students’ conception, it appears to be essential to discuss natural occurrences of different kinds of radiation. This includes nuclear background radiation as well as presenting light and heat as forms of radiation.

Evidently, discussing potential hazards of all kinds of radiation is an important part of science lessons. Nevertheless, positive aspects of radiation should not be omitted. Our research showed that radiation, in general, is very often considered to be dangerous to human beings. The fact that life would not be possible without light and thermal radiation should be discussed as well. Talking about applications of radiation in medicine and technology (also including nuclear radiation) can help students to get a differentiated view in their concepts of radiation.

The results of our interviews also revealed how difficult and implausible the concept of thermal radiation is to students. There was hardly anyone who believed that every object emits radiation, albeit harmless (at low doses). As this concept is essential to understanding basic relationships in science (e.g. the conservation of energy), we propose introducing this idea early in the science classroom. A good way of making this concept plausible could be demonstrated with the use of infrared cameras. Using pictures from IR cameras might make it easier for students to understand that every object emits some kind of radiation that cannot be seen but can be made detected with various instruments.

As a final remark, we would like to announce that the previously described study was replicated by our team two years later. In between the two parts of the study, the tragic events of Fukushima happened and one aim of the second part of the study was to investigate whether or not this accident influenced the students’ ideas. We plan to publish the results of the second part of the study including a comparison “before-after-Fukushima” in the near future.

References


Teaching Different Aspects of Light in the Unified Framework of Quantum Mechanics*

Marcelo Arlego, Instituto de Física- Universidad Nacional de la Plata (UNLP) - Argentina, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)- Argentina
Maria de los Ángeles Fanaro, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)- Argentina, Núcleo de Investigación en Enseñanza de las Ciencias y la Tecnología (NIECyT)
Maria Rita Otero, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)- Argentina, Núcleo de Investigación en Enseñanza de las Ciencias y la Tecnología (NIECyT), Facultad de Ciencias Exactas UNCPBA- Argentina

Abstract

In this work we present an analysis of various aspects of light in a unified and nontraditional framework. This will be the starting point of a methodological approach to the subject in Secondary School. First we start by showing a set of experimental results where light exhibits particle-like characteristics in certain cases and wavelike behavior in others. We then present experiments where light shows a “special” character that cannot be completely associated with either waves or particles, and without analog in macroscopic world, called “quantum behaviour”. In the second part of the work we show how to describe these different aspects of light from a single formulation: The quantum theory of light. To this end we adapt Feynman’s path integrals formulation. Our approach emphasizes the conceptual aspects, reducing mathematical content to the use of vectors.

Introduction

The Feynman method has been used in previous works for teaching quantum mechanics (Taylor, 1996, Taylor and Tuleja, 2004; Hanc, 2006, Hanc and Taylor, 2004; Hanc and Tuleja, 2005, Ogborn, Hanc and Taylor, 2006). The present work is a continuation of a series of investigations that we have carried out analysing the problem of teaching basic aspects of quantum mechanics in Secondary school, focusing on quantum behaviour of electrons (Arlego, 2008; Fanaro, Otero, and Arlego, 2009, 2010). Thus, based on Feynman’s path integral approach, a conceptual structure of reference (CER) (Otero, 2006, 2007, 2008) was reconstructed with the aim of promoting the conceptualization of the electron as quantum object and the study of classical-quantum transition.

Now our goal is to propose a new CER and use it as a basis to design, implement and evaluate a conceptual structure proposed for teaching (CSPPT) (Otero, 2006, 2007, 2008) the behavior of light from a quantum point of view. This approach is again based on path integrals formulation, adapting and contextualizing it in a variety of situations for high school students.

The particularity of the proposal presented here, is that we do not mention the term photon or phrases like particles of light, wave-particle duality or dual behaviour, to prevent students from interpreting light as “small” localized particles (in a classical sense).

The Conceptual Structure of Reference (CSR) to address the “Quantum” behaviour of light

First of all let us stress that we will refer only to properties of light, avoiding asking: What is light? as it is unfortunately common in Secondary school textbooks. In Physics such a question is meaningless, being of ontological and epistemological character. The point of view of physics is to construct models that describe observed phenomena and predict new ones.

* This paper is based on our previous work: Arlego, M; Fanaro, M, Otero, M R (2011) Enseñar el comportamiento de la luz en la escuela secundaria desde una visión actual utilizando el método de caminos múltiples de Feynman Actas I Congreso Internacional en Enseñanza de las Ciencias y la Matemática- II Encuentro Nacional en Enseñanza de la Matemática.

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We start showing a set of experimental results where it is possible to assign to light characteristics associated with particles in some cases, and to waves in others: typically laser light reflecting off a mirror or in a double slit experience, respectively.

But there are other situations where previous association is not possible. A paradigmatic case of this type is the double slit experiment with very low intensity of light. For didactic purposes we can consider it as a standard double slit experiment where we register the temporal evolution of light distribution on screen. Figure 1 shows a sequence of snapshots of detection screen in this experiment.

![Figure 1. Sequence of snapshots of detection screen at increasing times in a double slit experiment with very low light intensity. Initially the detection of light events seems to distribute randomly on the screen, analogously to “particle” impacts (left). But as time goes by the formation of an alternated pattern of maxima and minima on the screen that is characteristic of waves is evident (right).](image)

As it can be observed, the individual events are initially distributed randomly on the screen. But as time advances the formation of a pattern of alternated bands of maxima and minima of intensity of light occurs. In some aspects, it shows granular features, as the individual detection events on the screen (also the emission process of light from the source). But in others, it exhibits wave-like characteristics as the resultant pattern of alternated maxima and minima formed on the screen. This experiment shows that it is not possible to assign purely wave or corpuscular aspects to light, and therefore impossible to reconcile it completely with the usual concept of particle or wave. This characteristic of light is called “quantum behaviour” and it also applies to what is ordinarily considered matter (Fanaro, Otero, and Arlego, 2009).

**Quantum theory of light: Sum of all paths viewpoint**

In this section we postulate the laws that will allow us to describe the different aspects of light behaviour previously presented in a unified framework. We take as a base the concepts of the formulation of “Sum of all paths” of Feynman’s quantum mechanics (Feynman, 1985; Field, 2006). Before enunciating the laws, we need to specify some previous concepts.

**Events:** Quantum mechanics considers events. For example, in the experiment of the double slit with light of low intensity (Fig. 1) an event can be the detection of light from the source in a given point of the screen.

**Probability:** The quantum mechanics does not predict the certainty but the probability of an event. Again in the previous example, it is possible to predict the probability that the detection of light in a given point of the screen occurs.

Comparison theory - experiment: The predictions of the theory are compared with the experiment as follows: If $P(e)$ is the probability that the theory predicts for the occurrence of an event, then $P(e)$ tends to the quotient $Ne/N$, being $Ne$ the number of times that the event happens in the experiment and $N$ is the total number of registered events. In the example of the Fig. 1 if $e$ is the event of detection of light in a given point, $Ne$ is the observed number of times that light is detected in the above mentioned point and $N$ is the total number of detections (on the whole screen). If we do the quotient $Ne/N$ for every panel of the Fig. 1 the above mentioned quotient will have to tend to the value $P(e)$ predicted by the theory. Thus, we corroborate that the theory agrees with the experiment.
The rules of quantum mechanics to calculate probabilities: Having discussed how to compare theory and experiment, now we will consider quantum mechanics rules to calculate $P(e)$. To simplify the presentation we will restrict the behaviour of light in a vacuum, though all the concepts are easily generalized to other situations. We will consider a particular event $e$, being the detection of light in a screen point $F$, that has been emitted in $I$.

- **Multiple Paths:** Figure 2 shows some paths or alternatives that connect $I$ with $F$.
- **A vector for every path:** We associate a vector of two dimensions with every path. The length of the vectors is always the same as it does not depend on the path. We can arbitrarily assign to them for questions of simplicity, module 1.
- **The direction of the vector is proportional to the length of the path:** The angle of the associated vector to a path (measured conventionally respect to x-axis) is proportional to the length of the path. The proportionality constant is an intrinsic property of the light. For the time being we will only say that it will take different values for different “types” of light: red, green a “others” that our eye does not detect. But we do not need to know this value to continue with our reasoning.
- **Summing the contributions of all paths:** Next we add the vectors associated with all possible paths connecting $I$ with $F$. Thus, we get the resultant vector. Figure 2 (right) shows this sum for some selected paths.
- **From resultant vector to the probability:** The square of the length of the resulting vector (see Figure 2 right) is proportional to the probability of the sought event. In principle all paths connecting the initial and final state must be considered to calculate the resultant vector and hence the probability. This raises the problem of adding infinite vectors. In the next section we will see how we can “approximately” calculate the probability.

In short: we must consider all paths connecting $I$ with $F$ (in Fig. 2 a few are shown). We associate every path with a vector of unity length and direction proportional to the path length. Then we add all these vectors, and the squared length of the sum vector is proportional to the looked probability.

Note that the paths around the minimum make the major contributors to the sum as illustrated on the right of Fig. 2, which in most cases simplifies the sum calculation as we will see in the following section.
Some useful approximations: The special role of the shortest paths

In Figure 2 we have coloured some paths red. Why are these paths special? In the centre is the shortest path, which is a straight line. In the surroundings there are some paths that have approximately the same length as the line (due to its proximity). Since we have seen that the direction of the associated vector with a given path is proportional to its length, the vector of the straight line and its surrounding have substantially the same direction. What about the other paths marked in black in Figure 2? These have no relation to each other, they are of completely arbitrary length and hence their associated vectors appearing in arbitrary directions. If we could add “all” the possible paths, would see that the contributions of paths remote from the shortest tend to cancel each other.

The final result would be that only the contribution of the shortest way and those nearest to its environment contribute to the final sum and therefore to the probability. This idea is exemplified by a few paths in Figure 2 (right), where we have graphically added the vectors, then placing one behind the other (method head-to-tail). The resultant vector goes from the beginning of the first one to the end of the last one. Graphically, the area marked with orange in this figure will be proportional to the probability of detecting light in F, having been emitted in I. The constant of proportionality is not important; comparing areas related to different events we have the relative probabilities of the different events. For example, if an event 1 has associated an area that is the double of an event 2, it will mean that the probability of the event 1 doubles that of the event 2.

Description of the light in a unified frame

In this section we will analyze the different aspects of the light that can be observed experimentally, assuming the point of view of the rules of sum of paths of the quantum mechanics of the light mentioned above.

- The law of reflection reconsidered: The shortest path is the most likely

First, we consider the reflection of light, the incidence angle is equal to the reflection angle. We want to analyze whether there is any probability of an event where the angle of incidence is different from the reflection. Although this does not seem possible according to the experimental results, we want to analyze the quantum mechanical predictions for reflection. To analyze the situation from the view point of the sum of paths, let’s consider events of detection of light a and b as shown in Fig. 3 (top).

Figure 3. The reflection law from a quantum point of view. Top: Two possible points of reflection a and b. Middle: The variations of length are minor about the shortest way (b). Bottom: As consequence of the length of the resultant vector (therefore the probability) of reflection in b is greater than in a.

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Point b is the one that satisfies the “classical” law of reflection, whereas the event of detection in a does not follow the law of reflection. To calculate the probability of detection we would have to consider all the paths that go from the source to the detector through point a. Instead of considering all the contributions, we will use the approximation that we have analyzed in the previous section: of all the paths that contribute to the sum, the most important is the shortest path and those in its nearby environment. This is shown in Fig. 3 (top), where we have highlighted the shortest path and two paths at each side. To find the probability of detection in b we follow the same procedure considering the shortest path about b, as shown in the same figure.

In the middle of Fig. 3 the lengths of the considered paths for the cases a and b are shown. We observe an important difference between these cases. Around the shortest path (b) there are small changes of length. Nevertheless, around a the changes are greater. This can be verified measuring the ways directly. The consequence of these differences is seen in Figure 3 (low). In case b being the lengths much alike, its associate vectors (whose angle is proportional to the above mentioned length) point approximately in the same direction. This leads to a resultant vector, area and then big probability for this event. In comparison with case a, the major variations of the lengths in the paths generate major changes in the vectors, so they contribute less in the sum, resulting in a minor probability for this event.

This allows us to conclude that, from the quantum point of view, both events are possible, though the event in which the angles of incidence and reflection are equal, that is to say the shortest way is the most probable. If we made an extremely careful experiment, we might detect light in other points that do not follow the ordinary law of reflection. Therefore, the law of reflection, which we have associated with behaviour of particle from a macroscopic point of view, is an approximate law. We will not discuss in this work the range of validity of this approximation. Simply we will say that the laws of the quantum physics that we have enunciated frame this aspect of “particle” in a more general formulation, which allows to determine in what conditions this character of particle becomes evident or not.

- **Ondulatory behaviour without waves**

In this section we will analyze the double slit experiment from the point of view of the quantum mechanics. The formation of a pattern of maxima and minima of intensity of light on the screen is on the one hand consistent with an ondulatory phenomenon. In fact usual description of this phenomenon is in terms on classical electromagnetic waves. But on the other hand, we have seen that when the above mentioned pattern is analyzed in detail or with light of very low intensity, it seems to form from individual and located events (Fig. 1). Our aim is to analyze this statistical character of the phenomenon and the emergence of maximums and minimums on the screen using the rules of the quantum physics that we have enunciated.

Let’s consider Figure 4. It is supposed that the light is emitted from a source that is far left of the double slit screen. Those regions on the detection screen (on the right) where there is higher (lower) intensity are equivalent, from the point of view of our rules, to those points where it is more (less) probable to detect light from the source.

To calculate the probability of detection at a given point of the screen first we have to calculate the sum of the vectors associated with all paths connecting the source with the point on the screen. There are two direct paths that go from the source to a given point on the screen. Figure 4 shows these alternatives. One path is the one that goes from the source and passes through the slit below and the other one passes through the top. Of course there are many other alternatives, for example going out of one of the slits and taking a completely arbitrary path to reach the source. However we know from previous discussions that the shortest path and its environment are the most important. Then we will only consider the contributions of the two main paths (even disregarding the environment of each one) to calculate the probability. We will see that even with these approximations we will be able to describe the pattern of maxima and minima observed.
Maximum probability: In the difference of paths (green) the vector (blue) gives an entire number of turns

Minimal probability: In the difference of paths the vector gives an entire number of semi-turns

Figure 4. The double slit experience from the point of view of sum of ways of the quantum mechanics. Left: The vectors associated with the contributions of both slits come with equal direction (opposite) to the screen, giving a (minimal) maximum of intensity of light. To make this possible, (in the difference of paths, in green colour,) the blue vector associated with the bottom slit, must give an entire (semi-entire) number of turns.

First, let’s analyze in which conditions we would find a maximum in a point on the screen. According to our rules the vectors associated with the two paths that go from each slit should point in the same direction. A case where this will happen is in the centre of the screen, why? Because the distances of the slits to the centre of the screen are equal and their associated vectors then rotate the same angle so that their sum and hence the probability is maximum. That is, our theory predicts a maximum in the centre of the screen and this is observed experimentally. Now, how can we explain the presence of other maxima? Is there any possibility that although the distances are different the vectors keep pointing in the same direction? They do. In fact as we will see there are many ways this can happen. To understand this, let’s consider Figure 4 on the left. As it can be seen the lengths of both paths are different. In fact we have marked with green the difference in lengths. Also in Figure 4 vectors have been drawn at the beginning, at some intermediate stage and at the end. With blue colour we identified the associated vector to the bottom slit, and with red, the vector associated to the upper slit. At first both vectors are horizontal but will keep turning proportionally to the way that they are covering. Suppose a special but possible situation: the green distance is such that after going over the said distance the vector makes one turn, thus being horizontal once again (Fig. 4 left). In the rest of their respective paths both vectors will turn likewise (because they both need cover the same distance). The result is that they will get to the screen with the same direction and again generate a maximum of light intensity. Now we are going to generalize the idea. Those points on the screen that in the difference of paths (green) the vector below turns an entire number of times will give a maximum of intensity, because those are the most likely places where light will be detected.

The condition of minimum intensity on the screen is obtained by an equivalent reasoning. Figure 4 (right) illustrates this case. If in the difference of paths the vector associated with the down slit gives half of a turn (or an entire number of semi-turns) then the contributions of both slits on the screen will be equal and opposite, giving a minimum of probability (and intensity). The previous reasoning describes the distribution of maxima and minima on the upper half of detection screen. Exchanging the roles of the upper and lower slits, we realize of the distribution of lower half of screen. Any intermediate situation between maxima and minima can be interpreted in the same way, as addition or partial cancellation of the vectors associated with the straight ways across both slits, due to the
difference of lengths of the above mentioned paths. It is very simple to write mathematically the condition for the appearance of maxima and minima, which gives way to the observed alternation. Nevertheless it is more instructive in this stage to describe the observed phenomenon by means of the sum of vectors.

As in the case of the reflection it is possible to analyze the conditions under which it is obtained or not a distribution of maxima and minima in the double slit experiment, which is related with the “type”, slits distance, etc. This aspect relates to the limits of validity of the wave optics and we will not consider it in this introduction to the topic.

An aspect to stand out of the analysis by means of sum of paths that we have made is that we can describe the emergency of a wave phenomenon, as it is the distribution of maximums and minimums on the screen, without the need to discuss an underlying ondulatory model.

**Conclusions**

From the CSR presented here we are reconstructing the CSPT to show students different experimental results with light where it can be observed characteristics that ordinarily we either associate with phenomena of particles or waves. Then, we will show another experience where the light would show a new character, impossible to deal from a point of view of particles or waves. To describe this variety of experimental results we take the most fundamental comprising point of view: the quantum mechanics.

To introduce the basic concepts of the quantum mechanics we have chosen the formulation “Feynman’s Sum of paths”. To simplify this formulation is possible to resort to graphical representations and to basic operations with vectors, which captures the essential aspects of the theory. By means of these graphical methods it is possible to describe and to predict the different situations arisen initially, and new others. Especially we propose to analyze with the students the law of reflection from the point of view of sum of paths, and to determine that the shortest path is not the only one possible, but it is the most probable. Finally we propose to analyze the experiment of the double slit from a quantum point of view, as it is possible to identify the statistical aspect of the phenomenon, accepting a wave behaviour and bypassing the traditional description by means of wave optics (as commonly dealt, for example Hecht, 2001). We strongly believe that this approach may introduce the quantum nature of light in a viable way to students. Simulation tools will be developed to help visualize the concepts involved avoiding mathematical formalism.

The ideas presented here will soon be implemented in high school with 16-17 year-old students after testing a sequence of situations we are working on. The analysis and discussion of educational and cognitive aspects designed to promote significant learning of the concepts involved is essential. Our current research is oriented in that direction.

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Quantum Physics Education Enlightens Physics Education*  

Marco Giliberti, Physics Department University of Milan  

Abstract  

A lot of difficulties that aroused in interpreting quantum physics from its very beginnings are still at the core of most educational presentations today. In this paper it is argued that most of the reasons of these difficulties are mainly due to the lack of consciousness about the proper and exclusive nature of those knowledge organizers that are called physical theories. This specific nature is here identified with their formalism and interpretation. From a historical point of view, in the developing of quantum physics, at least three steps can be singled out. 1) The old quantum physics: that is the set of facts and interpretations from about 1900 till 1925 with the background idea of the existence of the so called quanta. 2) Quantum mechanics: the non-relativistic theory that describes the behavior of a finite number of interacting particles. 3) Quantum field theory: the relativistic theory of quantum interacting fields. In this work, explicit examples of some well-known difficulties in quantum physics education will be made; they derive from mixing together the previous steps with great ingenuity and, moreover, mostly focusing on the old quantum physics. This is intended as a position paper in which a pre-condition for every educational reconstruction of quantum physics for teaching is proposed. In fact it is stated that, in order to understand and stress the meaning and the “reality” of the quantum physics, one has: first to choose a reference well established theory and, second to rigorously keep to its mathematical formalism. Moreover it is argued that the addition to quantum theories of many extraneous concepts and some common sense schemas, often comes from an ambiguous idea of nature, and of scopes and aims of the science itself.

Keywords: quantum physics, education, theories, common sense schemes

Quantum physics education enlightens physics education  

Besides the well-known learning difficulties of students in classical physics, that come from well rooted common-way of thinking, many difficulties faced by most educational reconstruction of quantum theories have also other intrinsic epistemological reasons, that are mainly embedded in the so called paradoxes of the quantum world and that refers to very general (and not only common-sense) way of thinking. In this respect, even the teaching paths that do not follow a historical (sometimes it could be more exactly called a “pseudo-historical”) approach insisting on the first quantum models and problems, often lack a crucial point: that the meaning and the objective “reality” of quantum physics can only be read from the physics theory “adopted”.

Physics teachers, especially in pre-university schools, have to make students understand what physics has actually to say about the world. This point is almost clear for what concerns classical physics topics. For example in teaching mechanics one always refers to Newtonian mechanics and its three laws. Even when a historical introduction to the subject is made, in order to find a meaning to the concept of force one does not generally mix Aristotelian mechanics and Cartesian vortex theory with Newtonian mechanics. In a similar way, in teaching heat one normally refers to the four laws of thermodynamics, while treating electromagnetic phenomena one states on the Maxwell equations and the concepts involved in them (electric and magnetic fields, flux, circulation and so on). This means, for example, that the meaning of the concept of force is (as a state of fact) stressed from Newtonian mechanics and the “reality” of the electric field is understood through reasoning leading to, or starting from, Maxwell equations.

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On the contrary, in teaching quantum physics the situation is completely different: instead of relying on a precise theory, most of the teaching paths make a blend, of facts and interpretations coming roughly from 1900 till 1925, and of some ideas taken from quantum mechanics. I believe that an analysis of the reasons of this common way of teaching may help not only to improve our way of building educational paths on quantum physics, but to enlighten our classic physics teaching strategies as well. Moreover while in teaching classical physics often one relies on a substantially correct formalization (obviously in the most simplified version that is possible), in quantum physics teaching one pretends that this is not necessary. For example while no one would ever introduce forces without giving them the correct vector formalization, on the contrary, in quantum physics it is a common way of doing to speak about energy completely ignoring its operator character, (probably only because it is supposed it is too difficult for students!)

**Method: theories and quantum physics**

Science does not develop by reflecting from the beginning on its foundations, but mostly with the accumulation of facts and the accommodation of human beings to the new knowledge gained. Sometime, however, great contradictions are found, that once overcome, bring to a new knowledge or to a new Weltanschauung. When one faces contradictions it can be roughly said that he/she behaves “like a paramecium that meets an obstacle: at first he goes backward and then starts again to go forward in a direction chosen at random. One could advise him of a better direction, nonetheless what he knows is correct: he cannot go in that direction!” (Lorenz 1973). Now, as it is well known, with quantum physics science surely did face contradictions. An important example of that is given by the divergence between classical models of matter and the studies on the emission of light, that eventually gave birth to quantum mechanics (Ludwig 2008). The history of the paths taken by physicists to overcome this contradiction hides very different ideas and aspects. In fact, in the developing of quantum physics, at least three steps, three different ways of looking, can be highlighted.

1) The *old quantum physics*: that is the set of facts and interpretations coming from the late nineteenth century and the first quarter of the twentieth century linked to the idea of the so called quanta. Examples are the first solution of the problem of black body radiation given by Planck; the photoelectric effect with its explanation given by Einstein, and the various model of the atom, mainly the so-called Bohr’s atom. The *old quantum physics* is the first response given by physicists to faced contradictions, but by no means it constitutes a theory.

2) *Quantum mechanics*: that is the theory of atoms and electrons, generally known in the formulation given by Schrödinger and Dirac or in the one given by Heisenberg, Jordan and Born. It is a non-relativistic theory, with well-defined axioms, that describes the behavior of a finite number of interacting particles. It is interesting to remind here that there are many different formulations of quantum mechanics, i. e. matrix formulation, wave function formulation, path integral and second quantization formulation, and so on. There are even “non-orthodox” formulations like the one given by Bohm (Styer 2002).

3) *Quantum field theory*: the relativistic theory of quantum interacting fields. It is well known that every relativistic quantum theory will look, at sufficiently low energies, like a quantum field theory (Weinberg 1995). The most known example of a quantum field theory is quantum electrodynamics, and also the standard model of particle physics is formulated in the framework of quantum field theory. As it happened to *quantum mechanics*, there are many formulations of *quantum field theory* as well.

But now some problems come, because popular and even didactic presentation of quantum physics very often mix together these three previous steps with great ingenuity. Moreover they are mainly focused on the *old quantum physics* that, as stated above, is not even a theory, and therefore it can be in no way a reference “frame” for physics understanding.

Most of the problem comes from the fact that *i*) it is not possible to separate the object of knowledge from the instrument of knowledge: they must be considered as a whole thing (this aspect is one of the main teaching of quantum physics from its very beginning); and therefore that *ii*) theories are but mental constructions that help us find and define reality and utilize its resources.
Let’s give a closer look to this question. Physics inquiry begins with schemas and concepts that do not need to be explained by theories, because they come from common notions and language, or “common-schemes”. Then proceeds introducing other concepts by means of what can be call “pre-theories”, that are already known physics theories which are stated as granted. Pre-theories are unavoidable features of physics research and, for instance, they are at the basis of understanding of the working of measuring devices. Eventually, human inquiry arrives at the formulation of a new physics theory, that is determined by both, the basic concepts introduced before (common-schemes plus pre-theories) and some formalized well defined new disciplinary concepts able to explain old and new facts. “Actually we can imagine facts like icebergs, submerged under the surface of the sea of immediate experience that is perceived through common-schemes. The submerged part of these facts can only be hypothesized or, in a sense, imagined.” (Ludwig 2008). It is the previous, coherent and formalized, imagination of this under-the-sea level of reality that gives rise to physical theories.

Sometimes it can be useful to think of these imagined realities as fairy tales; in this sense “a scientific explanation is a story about how some entities, that are imagined but considered as real, would, by their very hypothesized nature, have worked together to generate the phenomenon to be explained” (Ogborn 2010). A very simple and clear example of that can be found in star constellations. We can see them in the sky and, moreover, they are useful in finding the way on open sea, but they are obviously man made constructions. Are they real? In what sense of the word real? Do they form “natural entities”? (Stenholm 2002). A way to answer to the previous questions is to think about the value of truth of a theory, that is the complete set of its mathematical formalism plus its field of applicability and plus the rules of correspondence between these two (Cavallini & Gliberti 2008). Thus: are star constellations elements of a theory? Is there a mathematical formalism to apply to them? Can previsions be made in a given field using star constellations? In a sense the answer is yes, in what we can call the geo-astronomical empirical theory used by ancient sailors with their measuring devices (the sextant for example) and some simple geometry. In this sense constellations are real “objects”. But the same theory that makes them “real”, makes them also “weak” objects, because it’s range of validity is narrow… in other more familiar words because constellations are not of so much practical or theoretical utility besides orienteering or, many times, story-telling and mythology.

A more physical and interesting example can be found in classical mechanics. In the mechanical description of the world, to the word force a reality in sé is often associated, as if forces were independent and external elements of reality. On the contrary, in physics, they find their meaning in the context of the Newtonian theory with its three principles. In fact, Newtonian mechanics is not a way to describe forces, but a conceptual scheme into which forces, by means of their formal connections with other elements of the theory, become part of reality (Cavallini & Gliberti 2008). In this respect, forces can be considered real quantities when the universe is described in the framework of that physical theory called Newtonian mechanics; but nonetheless they are only imagined entities outside that universe.

Turning back to quantum physics, another example is worth doing. When speaking of particles it should be clearly stated what it is meant by that word, that is what the theory, chosen as a reference theory, says about particles, what it allows to think about them, and what it does not. In particular one must be careful that with the word “particles” it is not implemented the idea that particles indicate physics entities in the sense of an ingenuous realism, and that these (ingenuous) entities coincide with the quanta of the theory, as it is often done in many quantum teaching paths.

One must be careful because “[...] our language describes an image [...]. It’s clear that, if we want to understand the meaning of what we say, we must explore the image. But the image seems to save us this effort; it already hints at a determined use. So it mocks at us” (Wittgestein 1967).

Therefore, when one teaches as if the macroscopic objects of our apparatuses and the conceptual objects of our theory were both real objects on the same footing, one misses the point. For instance, if in quantum mechanics one feels the need to explains how strange is the behavior of electrons, one misses the point; because that strange behavior of electrons (that is often referred to as wave/particle dualism) in quantum mechanics is, in a sense, postulated! Electrons are not “things” whose behavior one has to explain, but
elements of a theory with schemes (wave functions solution of a given Schrödinger equations in particular Hilbert spaces...) that is used to explain the physical world (i.e. to predict results of experiments). What sometimes is believed to be the object to be explained is, on the contrary, the basic ingredient by which phenomena are explained.

The situation is obviously different if the theory is changed. For instance in the quantum theory of fields electrons are again part of the theory, but this time they are a way to describe the behavior of normal modes of an interacting field. Therefore their epistemological status is now different from the one they had in quantum mechanics. And physicists go even further searching for a deeper theory...

The previous discussion does not imply that the abstract, “invented”, objects of a physical theory are not “real” (who would ever think that the microwaves emitted by a smartphone are not real?). On the contrary, in scientific construction, reality comes out of a set of coherent interpretations given in the framework (and with the formalism) of the reference theory; that is once a representation, given by the rules of correspondence between abstract concepts, experiments and results, is fixed.

In this way the abstract concepts pictured by the theory can be regarded as real (in the common-sense meaning of the word) as the macroscopic objects of our world. In fact, eventually, most of physics abstractions may even become part of the common-sense world, as it has happened with electromagnetic waves or gravity force, for example.

It is now easy to understand that reality becomes different with the time passing. In fact “the undetermined ‘mess’ to which we give the name ‘reality’ is subjected to continuous changes because the status of the supposed entities that should form this ‘reality’ is very flexible.” (Bellone 2006). Important and very known examples of these changes are the idea of absolute time, that of heat and the very idea and structure of the atoms.

It is easily to understand that difficulties can obviously emerge when one begins to believe in the very objective existence of the concepts of a theory (i.e. constellations for sailors, or forces for physicists) as they were natural entities independent of human scientific schemes. Luckily enough, the fact that even many physicists were unaware of these questions regarding the objectivity of the world and therefore have often looked at their results as at objective facts, has not prevented the development of physics. However it should be clearly stated that when this attitude is put forward even to quantum physics, our understanding of the world explodes into paradoxes. In this sense the lesson received by quantum physics is of great importance as it enlightens the way our theories work and helps the epistemological reconstruction of physics for teaching.

**Results: a zeroth order step for quantum physics education**

Instead of working starting from the general mess of the old quantum physics, it is here proposed that before any educational reconstruction of the topic, as a zeroth order step, a reference theory in one of its formulation has to be chosen, the concepts of the theory in this formulation must be identified and their meanings must be understood inside this framework (Cavallini & Giliberti 2008; Michelini & Stefanel 2004).

In author’s opinion the quantum theory of fields is best suited than quantum mechanics for quantum physics education in general and, more specifically, at high school. One of the reason is that only in quantum electrodynamics the concept of photon can be well defined. Another one is that wave/particle dualism is more clearly expressed in terms of a quantized field as it is done by quantum field theory, than by wave functions. At the University of Milano the research group in physics education has been working on this subject since 1995 and many encouraging results have come (Giliberti & Marioni 1996; Giliberti & Marioni 1997; Giliberti 1997a; Giliberti 1997b; Giliberti 1998; Bergomi & Giliberti 2001; Giliberti 2002a; Giliberti 2002b; Bartesaghi et al 2004; Giliberti 2004a; Giliberti et al 2004b; Giliberti 2007; Giliberti 2008). Anyway in general, whatever the reference theory chosen, in physics education one has to try to avoid misunderstanding of ideas and words that are used by the theory, but come from previous conceptions (pre-theories, or even common sense) rooted in the biased idea that physics reality can be identified even out of a formal theory. On the contrary, as it has been previously pointed out, in scientific construction, reality comes out of a set of coherent interpretations of the formalism of the reference theory. For example,
turning back to the before mentioned question of the meaning of the concept of “particle”, it has to be to reminded that “particle” is both a technical and a common word, and as such it can be understood as a metaphoric word for what is meant by some concepts of the theory. But this is not correct. In quantum mechanics particles of the same “kind” are identical, not only because they have the same charge, the same mass, the same spin... but also because they are indistinguishable, even by means of their position. They are identical because they have the same physical properties. An example is given by a system with two electrons of different energy. For this system situation it can be said that one electron has a certain energy while the other has another different energy, but it is impossible to answer to the question: which electron has which energy? In fact, and in more formal terms, the wave function obtained by the exchange of the two electrons would yield the same predictions for the measurements of every physical observable. It is thus clear that the intuitive semantic content of the word “particle” given to the quantum mechanics quanta (in our example electrons) is not, in general, adequate.

From an educational point of view, and as a further example of the motivation for preferring quantum field theory to quantum mechanics for teaching, it can be said that it could be much clearer if we spoke of quanta as linked to the excitations of normal modes, as it is done in quantum field theory instead of referring to them in terms of wave functions, because in this way it would be more evident that they are identical and indistinguishable... and, moreover, have very little to do with the usual semantic meaning of the word “particles”. In fact it is the event of revelation of a quantum in a device that drove physicist to the use the word “particle”, thus giving a translated sense to a word coming from classical physics (and from common language).

Following the guide given by the formulation of a theory most of the paradoxes (in quantum physics, as it has been already said, more or less all coming from the wave/particle dualism) become not so central, with a great help for teaching. The same strategy should also be kept for classical physics education. In this way many misunderstandings could be avoided and more links with quantum physics also highlighted.

A remaining deep intrinsic difficulty

I’m not claiming that keeping in close touch with a quantum theory and with one of its representation all difficulties run away. Surely many conceptual and educational knots still remain, because physics has a lot of subtleties that are very difficult to grasp and to handle, especially in teaching, as a lot of researches in physics education have clearly shown. But what is to be stressed here is that in teaching quantum physics a problem which is even deeper appears, it is an objective problem that comes from the theory itself and not from learning/teaching difficulties.

In fact in formulating quantum mechanics (or even the quantum theory of fields) one has a dichotomy, because for the same formulation of quantum mechanics the physics world has to be split into two parts: the microscopic world of the system to be studied (of which a quantum description is given), and the macroscopic remaining world, made of measuring devices, laboratory apparatuses and so on, (of which, instead, a substantially classical description is given).

Quantum mechanics cannot even be formulated without this distinction. The problem is exactly this distinction, because the theory gives no indication on how “to cut the world”, where to put the line dividing the quantum from the “classical” world. To formulate the theory this line is needed, but wherever this line is put, difficulties are generated that are due to the fact that, at least in principle, even measuring devices should obey quantum mechanics. Quite obviously, in fact, to get information from a microscopic experiment an amplification process that leads to a macroscopic change of a measuring device must be produced; but, as even the devices are describable in terms of quantum mechanics, this leads to an aporia because it is not so simple to understand (at least in principle) what causes the measuring apparatus to behave classically. So, where and when and why must quantum mechanics leave the place to classical physics? Is there a macroscopicity parameter? These questions cannot be answered by the theory. Nor it seems, at least till now, by experiments (see for instance experiments of diffraction of macromolecules that show wavelike proprieties even if of a “large” size [Arndt et al1999] or the many quantum macroscopic proprieties of a superconductor).
So while the theory needs the world to be cut into a quantum and a classical part to be formulated, at the same time it is conceived as a (non relativistic) theory of everything. There is not enough place here to go further in this discussion that has been put in evidence just to say that some deep difficulties are still rooted in quantum mechanics itself. Therefore the claim that there’s really no need of making educational paths that, instead of presenting difficulties where they really are, generate confusion, mixing aspects, ideas and words coming from a too ingenuous vision of reality, can be made even stronger.

**Conclusions**

This paper is a call to realism. The aim is to stress that, as it is already done (some time unconsciously) for classical physics, when dealing with quantum physics education a specific formulation of the theory must be clearly followed. From this point of view quantum mechanics gives many important hints to improve even classical physics education.

In dealing with quantum physics one, among the many formulation of quantum mechanics or one among the formulation of quantum filed theory, is to be chosen (the author suggests the latter, for his more easily grasped epistemology, linked as it is to specific space time fields instead of instead that to to wave functions in the configuration space). The path to follow and the results obtained in experimentations are but secondary problems in this perspective: they simply come after.

Historical or conceptual presentations and educational reconstructions of quantum physics in pre-university courses cannot skip this point, as instead many times they do both because of an underlying idea of physics reality that is too ingenuous and because the theory that should be kept as reference (quantum mechanics or quantum theory of fields) is a priori judged too difficult to be presented at school.

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Assunta Bonanno, Physics Education Research Group, Physics Department - University of Calabria, Giacomo Bozzo, Physics Education Research Group, Physics Department - University of Calabria, Michele Camarca, Physics Education Research Group, Physics Department - University of Calabria, Peppino Sapia, Physics Education Research Group, Physics Department - University of Calabria,

Abstract

In this work we present a series of integrated experimental activities on magnetic induction, aimed to address both Foucault's eddy currents as well as some specific issues on the magnetic field flux through an open surface. The learning path design (articulated in two different experimental setup) is suggested by some questions arose by students within a preceding learning activity at the University of Calabria. Proposed experiments are based on the use of a common USB oscilloscope and a commercial-grade high-speed video camera. The joint analysis of recorded video of a falling magnet crossing a drilled aluminum disk, and of electrical signals induced by it, allows significant didactical insights of the fundamental induction phenomenon. Furthermore, Foucault dissipation measurements are executed for different values of the disk's temperature, so highlighting the dependence of the phenomenon on the resistivity of the material. Proposed activities, suitable either for high school students or university freshman, allow teachers to exemplify and quantitatively discuss several topics, ranging from the magnetic flux's variation, to the thermal behavior of Ohmic conductors, and the energetic issues related to eddy currents.

Introduction

Physics Education Research recognizes the importance of experimental activities, since they promote the development of practical skills and stimulate scientific inquiry methods, in addition to having a great motivational value (Euler, 2006). Laboratorial activities, moreover, besides being an important source of knowledge in the physics teaching/learning process, help visualize abstract concepts and also challenges naïve beliefs of students (Michelini, 2005). In particular, this holds for the phenomenon of electromagnetic induction, for which the literature (Michelini & Viola, 2007; Stefanel, 2008; Bonanno et al, 2009) clearly identifies the main difficulties encountered by learners in dealing with this fundamental concept. Furthermore, as argued in a previous work (Bonanno et al, 2011a), didactical difficulties arise especially in facing the role of the time variation of magnetic field flux in experimental configurations where the idea of “circuits” corresponds to the various possible paths of electric currents flowing inside the bulk of extended conductors (Bonanno et al, 2009; Bonanno et al, 2011a; Bonanno et al, 2011b; Galli & Kaplan, 1997; Maloney et al, 2001; Thong & Gunstone, 2008; Michelini et al, 2009). In such a case, in fact, “circuits” are not immediately viewable, so that it is not obvious what are surfaces through which magnetic field flux is to be considered. An effective teaching methodology, aimed to face these issues, is represented by the introduction of an experimental path which links electromagnetism and classical mechanics, since intuition regarding dynamics and kinematics is much better developed from daily experience (Bonanno et al, 2011a; Tomasel & Marconi, 2012). A paradigmatic example of this situation is represented by the Foucault eddy currents flowing in a conductor body immersed in a variable magnetic field. This phenomenon plays a fundamental role in many interesting applications (such as induction furnaces, electromagnetic braking, magnetic levitation, evaluation of coating thickness, and so on), as well as in cases where eddy currents have deleterious effects, such as power loss in transformers’ magnetic cores. Due to its importance, this topic has been widely treated in didactical literature (Tomasel & Marconi, 2012; MacLatchy et al, 1993; Hahn et al, 1998; Pellicer-Porres et al, 2006; Levin et al, 2006; Roy et al, 2007; Aguirregabiria et al, 1997; Gonzalez, 2004; Caldwell, 1996; Vidaurre et al, 2008; Muiznieks & Dudareva, 2012), but proposed experimental demonstrations present some critical issues from a didactical point of view, namely: i) the underlying physical concept (i.e., electromagnetic induction), at the origin of the
observed dissipative phenomena, tends to be obscured if these experimental demonstrations are mainly focused on eddy currents (which are only an “effect” of e.m. induction); ii) proposed experiments rarely allow learners to perform quantitative determinations (Bonanno et al, 2011a; Tomasel & Marconi, 2012; MacLatchy et al, 1993).

The new learning path we present here, designed to overcome these critical issues, has also been inspired by some questions posed by undergraduate students at the University of Calabria, after they made some experiments on e.m. induction and eddy currents, described in two previous works (Bonanno et al, 2011a, 2011b). The questions were:

a) how dissipated power relates to induced e.m.f. in the conducting body?

b) can temperature affect the Foucault dissipation?

Besides these questions, strictly related to eddy currents, a third collateral question arose from students, suggesting us that some confusion exists between the “cause” (induced e.m.f.) end the “effect” (eddy currents):

d) when a magnet falls through a conducting ring, does the induced e.m.f. in the ring depend on the ring temperature as well as on the magnet position and state of motion?

In the aim to answering these questions we have designed the innovative learning path on electromagnetic induction proposed in this paper, based on the paradigm of the “Prevision-Experiment-Comparison Learning Cycle” (PEC cycle) (White & Gunstone, 1992; Pintò & Surunach, 2001) and the Physics by Inquiry methodology (McDermott, 2001). As known, the three-phase PEC instructional strategy relies on a peer-to-peer learning method where students working in small groups are requested to make previsions for some particular situation, to conduct experiments regarding that specific situation, and then to compare their results with previsions and, if necessary, return to the prevision phase, repeating the cycle. In accordance with this paradigm, the experiments in the learning path are preceded by stimulus-questions.

Proposed experimental activities, besides overcoming described critical issues and students’ emerged difficulties, provide the following educational advantages: 1) gives teachers the opportunity to focus students’ attention on the difference between “causes” and “effects” in physical law interpretation; 2) allows students to perform precise quantitative determinations of dissipative effects of eddy currents, experimentally relating them to the induced e.m.f. signals; 3) gives students the opportunity to get trained with high-speed video-analysis and kinematical data processing, employing high-tech (but relatively cheap) devices and common use software, such as Tracker1 and Origin2.

This paper is arranged as follows. In Section 2, the experimental setup is described, both in the version for e.m.f. and kinematic measurements. An exemplificative overview of experimental results obtained with the described apparatus is given in Section 3, together with some reflections on the way the activities allow teachers to address students issues on electromagnetic induction. Conclusions are drawn in Section 4.

Experimental apparatus

The experimental apparatus consists of an Atwood’s machine, bearing at one end a cylindrical bar magnet, at the other end an adjustable weight which can be filmed to track the motion (Figure 2). This setup has been implemented in two different versions, respectively aimed to: 1) study the space-time pattern of induced e.m.f. around the axis of fall of a cylindrical magnet (induced e.m.f measurements); and 2) study the Foucault dissipation in a conducting body when that magnet falls through it (kinematic measurements). In the following we will describe the two versions.

1 http://www.cabrillo.edu/~dbrown/tracker/
2 http://www.originlab.com/
Figure 1.
The setup for e.m.f. measurements involves a drilled Plexiglas disk (diameter 20 cm, thickness 1 cm, central hole 2 cm wide) cut in 4 annular sectors whose external diameters were respectively equal to 6, 10, 14, 18 cm (Figure 1, details). On the edge of each annular sector a groove was carved on which were wound 20 turns of enameled copper wire (0.2 mm section), whose ends were brought outside of the disc. In this way a set of coplanar and concentric coils were obtained, each of which can be singularly connected to a digital oscilloscope. The radially resolved e.m.f. sensor (RES) thus obtained was then positioned coaxially to a vertically mounted plastic tube, in which a cylindrical magnet could drop, hanging from one end of an Atwood’s machine (figure 1). This device, due to its cylindrical symmetry, allowed us to experimentally obtain the value of the electric field induced by the falling magnet, starting from the measurement of the e.m.f. The geometry of RES and the use of a suitable digital oscilloscope allowed us to resolve both spatially and temporally the induced signal. In particular, for the signal acquisition we used a Velleman PCSU1000 digital storage oscilloscope module that, connected via USB to a computer, constitutes a cheap digital oscilloscope allowing to acquire the induced signal and store it in a text file for subsequent data processing. The experimental setup for kinematic and dissipation measurements features a drilled aluminum disk (diameter 20 cm, thickness 1 cm, central hole 2 cm wide) through which the magnet falls (Figure 2). To take kinematic measurements as a function of temperature, involved disk was kept in a domestic freezer at -10 °C, then removed and inserted in the experimental apparatus located in an environment at 28 °C. After about 5 minutes its temperature (measured with a thermocouple located halfway between the center and the edge of disk) was -5 °C and the first measurement was made. Then subsequent measurements were taken every 5 °C, as the disk temperature gradually increased till 25 °C. Since a kinematic measurement (i.e., filming the counterweight motion through an height of the order of 50 cm) lasted less than half a second, while the disk temperature increasing rate was of the order of 1 °C/min (in the worst case, i.e., at low temperature), the disk temperature during the measurement was very nearly constant and homogeneous, within the resolution of the used thermometer (0.5 °C). These conditions were ensured by the sufficiently high heat capacity of the disk and by its shape. Such a
characteristics, in fact, allowed us to easily insure an uniform and controlled temperature in the whole body (this conditions could be difficult to achieve in metallic pipes employed in previous similar experiments). The motion of the counterweight (linked to the falling magnet on the other side of the Atwood’(*) StreamView-LR™ high speed camera. The film (acquired at a frame rate of 700 fps and a frame resolution of 640x120 pixels) was analyzed by using the Java-based, multi-language available, Tracker video-analysis tool. Since high-speed filming is characterized by very short exposition time (400 µs in our case), the luminosity of the scene to be filmed represents a critical issue. To reduce the impact of this problem the first precaution to be adopted is the use of a suitable light source, both from the point of view of the radiated power and from that of its spectral composition: we used a fluorescent lamp, whose 5000 K color temperature better matches the camera’s CCD spectral sensitivity.

Results and discussion

Described apparatus permits teachers and students to perform many kinds of measures (and subsequent elaborations), addressing different didactical issues. In this paper we shall give only a selection of them, addressed to answer some relevant questions emerged in some previous activities with students (Bonanno et al, 2011a, 2011b), as already mentioned in the Introduction. For a broader discussion we refer to a forthcoming article (Bonanno et al, 2012).
A first group of significant questions identified in the students’ works concerns the e.m.f. signal induced in a coil by a magnet vertically falling through it along its symmetry axis (figure 3). Relevant questions are:

- **Q.1** *In the time domain, does the position of structures labeled as A and B depend on coil radius?*
- **Q.2** *Do the peak intensities increase for increasing coil radius?*
- **Q.3** *Do the peaks broaden for increasing coil radius?*
- **Q.4** *Does the peaks’ intensity ratio depend on the coil radius?*

Besides the dependence on coil radius, the same questions appear in students’ work, asking about the possible dependence on the falling height. To give a meaningful example of the learning path application, in the following we report on the measures answering to questions Q.1-Q.4 (answers to similar questions, regarding falling height’s effects on the induced signal, can be readily obtained by performing appropriate measurements).

The correct answers can be immediately deduced from the analysis of signals acquired with the experimental setup described in Figure 1. Signals from the different coils of the RES were singularly acquired by the digital storage oscilloscope and then aligned at the instant in which the e.m.f. vanishes, because for all the coils this instant corresponds to the passage of the magnet center across the coil plane. Figure 4 shows these signals as a function of time during the falling motion of the magnet. The upper part of the figure shows each signal with its own amplitude, so that peak amplitudes are directly comparable. In the lower portion of the figure, instead, the same signals are shown, normalized so to have the same peak amplitude; in this way, an immediate comparison can be made among signal widths. The first feature to highlight in these figures is that both positive and negative peak positions coincide for different coils. This answers question Q.1, in the sense that the maximum of induced e.m.f. (and, consequently, the maximum of induced electric field) is reached at the same instant throughout the plane perpendicular to the magnet’s fall axis. In particular, the knowledge of the position of the magnet as a function of time (obtained, as we shall see in the following, by means of the high speed video analysis) allowed us to show that peaks of the signal correspond to the passage of the two magnet’s poles through the coils’ plane. Similarly, Q.2 is readily answered looking at the top portion of figure 4, since peak’s intensity decreases for increasing coil radius.
Furthermore, Q.3 and Q.4 can be answered by looking at the bottom part of the same figure, clearly showing that peaks are broader for larger coils, while the intensity ratio between positive and negative peaks is independent on coil radius.

An useful in-class discussion of the experimentally observed features can be done in terms of magnetic field lines and magnetic flux through the coils. The geometry of the field line pattern with respect to coils.
of different radius (figure 5), in fact, allows to understand why peak intensities are smaller for larger coils. Similar geometric reasoning can be done to qualitatively explain the observed behavior of the peaks’ widths and amplitude’s ratio.

Let us now look at an example of results obtained with the experimental setup designed for kinematic and dissipation measurements, shown in figure 2. This setup allows to answer to some questions arising from students when Foucault dissipation is involved, as the magnet falls through the drilled aluminum disk. An example of these questions is:

Q.5 *Does the Foucault dissipation depend on the disk temperature?*
To answer this (and some other related issues, see (Bonanno et al., 2012)) we used an aluminum disk whose temperature was made to vary from -5°C to room temperature. The high speed camera detected the position of the counter-weight when the magnet was dropped from a fixed height. The video analysis performed with Tracker allowed us to obtain the law of motion of the falling magnet (Figure 6). Numerical derivation of these curves, done by means of the software Origin, given us the speed of the falling magnet as a function of the traveled length (Figure 7). Since kinetic energy is proportional to the squared speed, reducing speed (at a fixed height, and so at a fixed gravitational potential energy) results in reducing total mechanical energy, i.e., in increasing dissipated energy. So, Figure 7 qualitatively answers to Q.5, showing that Foucault dissipation increases as the conductor’s temperature is lowered. This behavior can be readily understood in terms of the Ohm’s law, since at fixed e.m.f. the Joule power dissipation is inversely proportional to the medium resistivity and, since this last reduces as temperature is lowered, dissipated power increases accordingly.

In this case also, a deeper quantitative analysis can be done of acquired data, getting more information on the Foucault dissipation and on its relation to the induced e.m.f. and to the local electric field. Since the aim of the present work is to give an overview of the educational potential of the proposed learning path, we will not provide details here, referring to a subsequent article (Bonanno et al., 2012) the interested reader.

**Conclusions**

In this work we describe an experimental learning path on electromagnetic induction, designed to address some learning problems arose among undergraduate university students participating in a previous experimental activity. A series of experiments, based on the fall of a bar magnet through a conductive aluminum disk, permits to answer some questions raised by students, so clarifying the meaning of magnetic field flux and its role in the e.m. induction phenomenon. In particular, the experimental setup is implemented in two different versions. The first version allows experimenters to measure the induced e.m.f. at various distances from the magnet’s axis of fall, in a plane perpendicular to it; the other version permits the determination of Foucault dissipation in the conductive disk at various temperatures, based
on the study of the magnet’s kinematics through high speed video analysis conducted by means of the software Tracker. A sample overview of the possible measurements, and of their interpretation, is given to exemplify the potential didactical employ of the proposed experiments. The comparison between e.m.f. measurements performed by a multi-coil sensor having the same spatial extension of the conducting disk, and the kinematic measurements done when the disk is present, give the context to clarify the causal connection between the fundamental phenomenon of e.m. induction and one of its possible effects, i.e. the Foucault dissipation when a conductor is involved. Last, proposed activities give students the opportunity to get trained with video-analysis, data acquisition and manipulation.

References


A New Way of Teaching the Special Theory of Relativity

Michael Pohlig, Schaafweide 21, D-76467 Bietigheim; michael.pohlig@kit.edu

1. What changes Newtonian Mechanics into the Special Theory of Relativity?

Usually, in introducing in the Special Theory of Relativity we begin by discussing the failure of the Michelson-Morley experiment. Fitzgerald’s hypothesis, elaborated by Lorentz stated that all bodies in motion should be shortened in the direction of their velocity. He believed this contraction to be caused by special molecular forces. Very different to this explanation was the assumption made by Einstein:

Axiom: The velocity of light in empty space is the same in all reference frames and is independent of the motion of the emitting body.

This axiom turns Newtonian mechanics into Einstein’s Special Theory of Relativity. Using this axiom, Einstein could prove the very important theorem:

Theorem: The mass of a body and the energy of a body are just different words for the same physical quantity.

The well-known formula for this theorem is:

\[ E = mc^2 \]  

(i)

In the Karlsruhe Physics Course Einstein’s axiom and theorem change places. The sentence - mass and energy are the same physical quantity - is now the axiom which changes Newtonian mechanics into Einstein’s Special Theory of Relativity and the sentence - the velocity of light in empty space is the same in all reference frames and is independent of the motion of the emitting body - becomes a theorem. For mathematicians such an exchange is not unusual. One reason for exchanging an axiom with a theorem is that it actually aids comprehension of the problem. This paper will show, that many important results from the Special Theory of Relativity can be developed from the axiom: Mass and energy are the same physical quantity.

Formula (i) is often misunderstood. People think the formula means that energy could be changed into mass or vice versa - mass could be changed into energy. Such an interpretation of the formula leads to error if it is used in the same physical system. It would mean that in a system energy could increase at the cost of mass and vice versa - the mass could increase at the cost of energy. This, however, is not correct. In fact, mass and energy are different words for the same physical quantity. The factor \( c^2 \) in formula (i) converts the unit Kilogram (kg) into Joule (J), nothing more. It would be better to write formula (i) as

\[ E = k \cdot m \]  

(i’)

The fact that \( c = \sqrt{k} \) is a velocity, with a certain role in Einstein’s Special Theory of Relativity, will become evident later. In school formula (i’) should be used; to save time and space formula (i) is used in this paper.

2. The role of momentum and energy in the description of bodies in motion

In Newtonian mechanics the primary concepts are trajectory, velocity, mass and force. Momentum and energy are nothing more than tools for easier calculations. In contrast to this, the Karlsruhe Physics Course is based on quantities which are primary quantities of quantum mechanics. These quantities have something in common, namely, each can be pictured as a kind of “stuff”. This is the reason why they are called “substance-like” [3]. Like any substance these quantities can be thought to be brought into a physical system, they can flow from one system to another and there exists currents of such quantities. Momentum \( p \) and energy \( E \), respectively, are such “substance-like” quantities. Their currents are traditionally called force \( F \) and power \( P \). We prefer to use the names “momentum current” instead of force and “energy current” instead of power. The pictures these names create in our minds are more practical than the ones created by the traditional names.
Here is a short summary of the most important rules pupils should know when they follow the Karlsruhe Physics Course:

1. A body in motion has momentum. If the mass and the velocity of the body are known, we can calculate its momentum by the formula:

\[ p = m \cdot v \] (ii)

A body with the mass 1kg and the velocity 1m/s has a momentum of 1Hy

2. Momentum can flow from one body to another, providing that there is a conducting connection between both bodies.

If in the time interval \( \Delta t \) the momentum \( \Delta p \) flows into a body, we say, the momentum current into the body is:

\[ I_p = F = \frac{\Delta p}{\Delta t} \] (iii)

The unit of the momentum current is 1Newton (\( 1N = 1 \text{Hy/s} \))

3. If momentum carries energy, the energy current is given by:

\[ P = v \cdot F \] (iv)

3 Model-building and the Karlsruhe physics course [4]

In this paper the model-building software Powersim™ [5] is used. A great advantage of a model-building system like Powersim and others like Stella [6] and Coach6 [7] is that models can be edited by using graphic symbols. Another advantage is that these flow diagram symbols, used by Powersim, allow us to build a picture of the substance-like quantities in our minds. In the model (Fig. 1) a level symbol is shown. It represents the quantity \( X \), the momentum \( p \) for example. An arrow leads from a cloud into the level symbol. If \( X \) is momentum \( p \), then there is a current of momentum and momentum will be accumulated. The fact that the arrow starts in a cloud shows us that it is not specified where the momentum current comes from.

![Figure 1. Some symbols of Powersim](image)

The model shown in fig 1. represents the following iteration loop: the rate of change \( \Delta X \) of \( X \) in a region is equal to the current into or out of the region, and the quantity \( X \) obeys a general conservation law.

\[ X_{\text{new}} := X_{\text{old}} + \Delta X = X_{\text{old}} + I_X(t) \cdot \Delta t \]

The loop will be executed from \( t_1 \) to \( t_2 \) with a time step \( \Delta t \). The initial value of the quantity \( X \), that is \( X_{\text{old}} \) for the first run of the loop, and the time step \( \Delta t \) can be chosen by the user of the program. The iteration loop will be executed automatically. This is programmed by editing the model using the graphic symbols, as shown in fig 1. Another advantage of the model building program is that \( I_X(t) \) must not be constant. When pupils first start to work with a model building system, very simple models should be chosen to familiarise pupils with such systems.
3.1 Free falling of a body - the non relativistic view

One simple example is free falling of a body. Fig 2 shows a stone hanging on gallows. The spring is stretched. Thus momentum is leaving the stone through the spring. Since nothing is in motion, no momentum is accumulated. If momentum is leaving the stone but the stone remains in rest, a momentum current of the same amount must enter it. Its value is:

\[ F = m \cdot g \]  

Here \( g \) is the acceleration due to gravity. If we cut the connection between the stone and the spring, momentum cannot leave the stone anymore, thus the stone will fall to earth. Using the equations (ii), (iii), and (v) we find \( v = g \cdot t \), the velocity increases linearly with time. This is shown by several well-known experiments.

Figure 2. Momentum flows through the gravitation field into the stone and through the bars back to earth.

Figure 3. View of a model in a Powersim application window: diagram (left) equations (right)
Fig. 3 shows the Powersim application window with two views of the model ‘free falling’ in the workspace, each in separate smaller windows. The left one, the diagram view, displays the model’s structure using the flow diagram symbols. The mass \( m \) and acceleration \( g \) are generated as constants, the velocity as a variable. Constants are displayed as rhombuses, variables as circles. The curved lines from the mass symbol to the velocity symbol and from the momentum symbol to the velocity symbol represent the links between these quantities. The velocity \( v \) is defined as:

\[
v = \frac{p}{m}
\]

The momentum must be initialized. Here the initial value is taken to be 0 Hy, this means that at the beginning of the simulation the body is not in motion. The momentum current is set to constant 10N and the mass to 2kg. Fig. 4 shows the simulation setup, that is: start time, stop time and time step. The iteration loop is calculated as a numerical integration. In the model we use the integration method RUNGE-KUTTA with variable step size\(^1\).

Figure 4. Simulation Setup

Figure 5. \( p-t \)-diagram (left) and \( v-t \)-diagram (right)

Powersim is able to display all kinds of time graphs, phase-diagrams and time tables for all quantities used in the model. In fig. 5 we see the \( p-t \)- and the \( v-t \)-diagrams for two different masses. As expected, the curves are straight lines and the \( v-t \)-diagrams are the same. We see, that the accumulation of momentum in a body during free falling leads to an increase in velocity. In other words: the increase in velocity indicates that momentum is accumulating. This is different to what is stated in EINSTEIN’s Special Theory of Relativity. As we will see, momentum can be accumulated in a body without the velocity increasing.

Fig. 6 shows the modified flow diagram. Energy is added as a variable. The result of the simulation is shown in fig. 7. The energy \( E \) is initialized with 0J and the energy current is given by \( P = F \cdot v \). Therefore \( E \) is not the total energy of the body but only part of it. This part is traditionally called kinetic energy.

The result of the simulation is displayed in a phase-diagram window (fig.7). Here we can see how energy is dependent upon momentum. It is clear that the curve, a parabola, represents the well-known formula:

\[ E = \frac{1}{2} m v^2 \]

\(^1\) See further information in [7] or standard books on numerical integration.
\[ E_{\text{kin}} = \frac{p^2}{2m} \]

This can be checked with the help of a table graph, generated by Powersim (see fig. 7).

Figure 6. Flow diagram - free falling of a body on the surface of earth. Powersim does not distinguish between normal letters and capital letters, so energy current is written as \( I_E \) instead of \( P \).

Figure 7. \( E-p \)-diagram (left). Table graph showing the last ten time steps of the iteration loop. The check column contains \( p^2/(2m) \) (right).

3.2. Free falling of a body on a neutron star - the relativistic view

When the Special Theory of Relativity is taught in schools, it is not possible to carry out any experiments. Therefore, computer aided model building provides us with a real alternative. Here, free falling of a body on the surface of a neutron star is chosen. There are two reasons for this: firstly, the basic model - free falling on the surface of the earth - is already known thus the model only has to be modified slightly. Secondly, from movies and science fiction, pupils are familiar with neutron stars at least by name. Fig. 8 shows the modified model. The mass of the body is no longer independent; rather it depends on the energy \( E \) due to

\[ m = \frac{E}{c^2} \]

\( E \) is no longer the kinetic energy, now it is the total energy of the body. The initial energy of the body is the energy contained in the body when it rests, that is, when its momentum is 0Hy. This energy is named \( E_0 \). In our model the value of \( E_0 \) is set to \( E_0 = 9 \cdot 10^{13} \text{J} \) and \( m_0 = 1 \text{g} \). The value of the acceleration due to gravity on a neutron star is set to \( g = 10^{12} \text{N/kg} \).
The results of the simulation\(^1\) (fig. 9) show that \(c\) is the highest velocity a body can reach, or, better: \(c\) is the border-velocity for all momentum-energy transport. In fig. 9 \(v\)-\(t\)- and \(m\)-\(t\)-diagrams are displayed for the rest energy \(E_0 = 9 \cdot 10^{13} \text{ J} (= m_1)\) and \(E_0 = 18 \cdot 10^{13} \text{ J} (= m_2)\) respectively. At the beginning of free falling, accumulation of momentum causes the increase in velocity while the mass remains almost constant. The linear increase in velocity in the beginning represents NEWTONIAN mechanics. Later, when the border velocity is almost reached, energy and momentum are still flowing into the body. Due to \(p = m \cdot v\), accumulation of momentum causes an increase in mass (=energy) only. When the velocity is nearly \(c\) the increase in mass represents 'high relativistic mechanics'. Fig. 9 (right) verifies this. While \(v\) tends towards \(c\), the mass grows infinitely\(^2\) (fig. 10 left). This singularity shows that \(c\) has the same value in all reference frames. If this was not the case a body could have 'nearly infinite' mass and it would not be possible to accelerate this body anymore, whereas the same body could be accelerated if it was seen in another reference frame.

\[ E_0 = 9 \cdot 10^{13} \text{ J} (= m_1) \]
\[ E_0 = 18 \cdot 10^{13} \text{ J} (= m_2) \]

\(^1\) The time of falling is 0.001s, therefore, as a result of the high velocity, the falling distance is so great, that a homogeneous gravitation field cannot be assumed. However all results are valid for any homogeneous acceleration field, for example an homogeneous electric field. The gravitation field of a neutron star was chosen for motivation.

\(^2\) The rate of acceleration of a body falling in a homogenous gravity field is contrasted to that of a body in a homogeneous electric field; as a result of the increase in mass while falling the momentum current into the body must increase in the same way. In a homogeneous electric field, the momentum current remains constant because the electric charge, by which the body is coupled to the electric field does not change its value while falling.
Figure 10. $m$-$v$- (left) and $E$-$p$-diagram (right)

Figure 11. non-relativistic and relativistic $E$-$p$-diagram

With increasing momentum all curves approach the asymptote $E = c \cdot p$ [8]. For particles which only exist at the velocity $c$, the formula $E = c \cdot p$ is exact. Photons are such particles. Energy and momentum of a photon are fixed by its frequency\(^1\), so the border velocity is found to be the speed of light. As $c$, the border velocity, is an universal constant, the speed of light must have the same value in all reference frames.

Figure 12. $E$-$p$-diagrams for the rest masses 1g and 2g. The asymptote is added

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\(^1\) Let a photon fall in a gravity field, its energy and momentum will increase, this is only possible by increasing its frequency (Doppler effect)
4. Proving the new way

A momentum current

\[ F = I_p = \frac{dp}{dt} \]

is always coupled to an energy current according to

\[ I_E = v \cdot I_p \]

or

\[ \frac{dE}{dt} = v \cdot \frac{dp}{dt} \]

or

\[ dE = v dp \]

This is better known as the Gibbs fundamental form of a system, all of whose independent extensive variables except \( p \) are held constant. According to \( E = m \cdot c^2 \) and \( p = m(v) \cdot v \) the Gibbs fundamental form changes to

\[ d(c^2 \cdot m) = v \cdot d(m(v) \cdot v) \]

Due to the evaluation of the differentiation and separation of the variables we get

\[ c^2 \cdot dm = v^2 \cdot dm + v \cdot m(v) \cdot dv \]

\[ (c^2 - v^2)dm = v \cdot m(v) \cdot dv \]

\[ \frac{1}{m(v)} \cdot dm = \frac{v}{c^2 - v^2} \cdot dv. \]

After integration we have

\[ \int_{m(v=0)}^{m(v)} \frac{1}{m} dm^* = \int_0^v \frac{v^*}{c^2 - v^2} \cdot dv^* = -\frac{1}{2} \int_0^v \frac{-2v^*}{c^2 - v^2} \cdot dv^* \]

\[ [\ln m^*]_{m(v=0)}^{m(v)} = -\frac{1}{2} \cdot [\ln(c^2 - v^2)]_0^v \]

With \( m(v=0) = m_0 \) we get

\[ \ln \frac{m(v)}{m_0} = -\frac{1}{2} \ln \frac{c^2 - v^2}{c^2} = \ln \sqrt{\frac{c^2}{c^2 - v^2}} = \ln \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \]
and at least we have

\[ m(v) = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \]  

(\text{I})

For \( v > c \) the square root in (I) is not defined. Therefore we have an important result: the physical meaning of the factor \( c^2 \), which was originally constructed to transform kg into J, is now found to be a special velocity - the border-velocity for all momentum-energy-transports, and if \( v \to c \) then \( m(v) \to \infty \). Thus velocity is a singularity. This means that \( c \) has the same value in all reference frames.

With (I) we have

\[ E(v) = \frac{E_0}{\sqrt{1 - \frac{v^2}{c^2}}}. \]  

(\text{II})

We substitute for

\[ \frac{v^2}{c^2} = \frac{v^2 \cdot m^2(v) \cdot c^2}{c^2 \cdot m^2(v) \cdot c^2} = \frac{p^2 \cdot c^2}{E^2(v)}. \]

and get

\[ E(v) = \frac{E_0}{\sqrt{1 - \frac{p^2 \cdot c^2}{E^2(v)}}}, \]

and at last we have the very important equation

\[ E(v) = \sqrt{E_0^2 + p^2 c^2}. \]  

(\text{III})

For a particle which exists only at the speed of \( c \), such a particle has no rest-energy, equation (III) is modified to \( E(v) = p \cdot c \). We will get the same relation if \( p^2 \cdot c^2 \gg E_0^2 \).

5. References


[5] Powersim; The Complete Software Tool for Dynamic Simulation; Powersim requires Windows 3.1 or higher. ModellData AS; P.O. Box 206, N-5100 Isdalstø, Norway

E-mail: powersim@modeld.no

[6] Stella for MAC Computers, but there exists a PC Version


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The Application Levels of Prospective Physics, Chemistry and Biology Teachers’ Zeroth and First Laws of Thermodynamics on Daily Events

Vahide Nilay Kırtak Ad, Physics Education Department, Balıkesir University, Balıkesir, TURKEY, nilaykirtak@gmail.com
Neşet Demirci, Balıkesir University, Balıkesir, TURKEY

Abstract
The purpose of the present study is to find out the application levels of prospective physics, chemistry and biology teachers’ zeroth and first laws of thermodynamics on daily events. The participant of the study where the descriptive survey model was employed consists of the 245 prospective teachers who were students in the Balikesir University at Necatibey Faculty of Education during the 2009-2010 academic years. In sampling selection, one of the purposeful sampling methods namely criterion sampling has been employed. Research data have been obtained via “Application Test of Thermodynamics Laws on Daily Event” developed by researchers. In data analysis descriptive analysis techniques have been used. Findings of present research showed that prospective teachers face difficulties in applying the laws of thermodynamics on daily events while explaining sample cases. It has also been determined that prospective teachers have some misconceptions and misinformation (Temperature and heat are the same thing. When the temperature of any object rises, there is no energy change. Energy is composed of kinetic and potential energy alone etc.). The pre-knowledge on thermodynamics that students have should be identified and the points they fail to figure out should be detected by developing new teaching strategies a more effective thermodynamics education should be achieved.

Keywords: thermodynamics, thermodynamics laws, zeroth law of thermodynamics, first law of thermodynamics, temperature, energy, daily event, misconception, misinformation.

Introduction
In our universities in Turkey, thermodynamics course is basically offered in science and engineering departments in addition to biochemistry and pharmaceutical departments as well. The abstract nature of thermodynamics concepts and the link of the course with advanced mathematics makes the teaching of thermodynamics harder (Sichau, 2000).

Due to the ambiguity in grasping the difference between heat and temperature students who start to attend thermodynamics classes mostly underline that thermodynamics is a challenging course (Carlton, 2000). Furthermore the tight interconnection between thermodynamics and daily life pose both advantages and disadvantages for trainers (Paik, Cho and Go, 2007). That stems from the pre-knowledge possessed by student may at times facilitate learning since this knowledge may occasionally trigger misconceptions (Chi, Slotta and Leeuw, 1994).

Aside from that, within the scope of the first law of thermodynamics, the presence of heat transfer, work and internal energy concepts under the same topic heading and the origination of all concepts from the same basic quality named energy may also push students towards a conceptual ambiguity (Loverude, Kautz, and Heron, 2001).

An analysis of thermodynamics-relevant studies demonstrate that these researches largely focus on misconceptions and teaching of concepts (Harrison, Grayson and Treagust, 1999; Sözbilir, 2002). In addition to the detection of misconceptions and achieving a better training it also bears importance to comprehend the way these concepts are applied to daily events since real learning can only start when students adapt their learning into different events or explain the daily events with the help of an acquired knowledge.
Purpose

The purpose of the present study is to find out the application levels of prospective physics, chemistry and biology teachers’ zeroth and first laws of thermodynamics on daily events.

In line with this aim below stated questions have been sought for answers:

- To what extent can prospective teachers carry out the zeroth and first laws of thermodynamics on certain daily events?
- What are the misconceptions and wrong ideas used in the zeroth and first law of thermodynamics?

Methods

The design of this study is a descriptive survey model.

“Survey studies ask large numbers of people questions about their behaviors, attitudes, and opinions. Some surveys merely describe what people say, they think and do. …” (Marczy, DeMatteo and Festinger, 2005)

Participants

The sample of this study consists of the 245 prospective teachers who were students in the Balikesir University Necatibey Faculty of Education during the academic years of 2009-2010. The distribution of the sample according to their department is given in Table 1.

Table 1. The distribution of the sample by the field department

<table>
<thead>
<tr>
<th>Department</th>
<th>Year</th>
<th>N (student number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology Education</td>
<td>1st year</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>2nd year</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>3rd year</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>4th year</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>5th year</td>
<td>13</td>
</tr>
<tr>
<td>Chemistry Education</td>
<td>4th year</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>5th year</td>
<td>20</td>
</tr>
<tr>
<td>Physics Education</td>
<td>3rd year</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>4th year</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>5th year</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>245</td>
</tr>
</tbody>
</table>

In sampling selection, one of the purposeful sampling methods namely criterion sampling has been employed. One of the criteria in sampling choice has been whether prospective teachers before took or were taking thermodynamics courses.

Parallel to this goal, prospective physics teachers who took “Heat and Thermodynamics” courses in third year; prospective biology teachers having taken “Environmental Education” course involving thermodynamics subjects in the first year and “Environmental Biology” in second year and prospective chemistry teachers who took “Physical Chemistry I” and “Environment and Humans” in third year have been included in research scope.

Instrumentation

Research data have been obtained from “Implementing Thermodynamics Laws on Daily Events Test” which is developed by researcher. In this test, there were six open-ended questions related to implementation of the zeroth and first laws of thermodynamics on certain daily events. Questions in this test are given in
Table 2. Questions on the test

<table>
<thead>
<tr>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st question</td>
</tr>
<tr>
<td>2nd question</td>
</tr>
<tr>
<td>3rd question</td>
</tr>
<tr>
<td>4th question</td>
</tr>
<tr>
<td>5th question</td>
</tr>
<tr>
<td>6th question</td>
</tr>
</tbody>
</table>

The analysis of the answers given to these open-ended questions has been made with respect to the feature in question, and then prepared rubrics. Some sample answers from prospective teachers have also been given in the next section.

Findings and Interpretation

This part consists of two sections as findings and interpretations related to the zeroth law and first law of thermodynamics.

Findings and interpretation related to the Zeroth Law of Thermodynamics

Findings and interpretation on the first question related the zeroth law of thermodynamics is given in this section.

First question in the test

Prospective Physics, chemistry and biology teachers’ answers to the question “Could you explain how to measure the temperature of an object using a thermometer?” were categorized according to the answers given (correct, partially correct, recurring or not wrong answer, wrong answers, not coded/unanswered and irrelevant answers) and were presented along with their percentages and frequencies in Table 3.
### Table 3. Findings on the first question

<table>
<thead>
<tr>
<th>Correct Answer</th>
<th>Department</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Physics Education</td>
<td>Chemistry Education</td>
<td>Biology Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td>Explained by heat exchange and thermal balance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat exchange between the ambient temperature and thermometer’s temperature occurs when we put the thermometer in the environment. After a while, thermal balance is provided. Mercury in the thermometer ascends or descends through by dilution. (F31)</td>
<td>4</td>
<td>7.7</td>
<td>1</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>Partially Correct Answer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explaining the situation just through thermal balance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Until the thermometer reaches the thermal balance, it ascends along with the effect of mercury. In it and measurement, can be taken once the balance has been achieved. (F49)</td>
<td>10</td>
<td>19.2</td>
<td>2</td>
<td>4.4</td>
<td>13</td>
</tr>
<tr>
<td>Explaining the situation through heat exchange and thermal balance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat exchange between the thermometer and a substance occurs. Temperature can be measured when the thermal balance is achieved. (F17)</td>
<td>8</td>
<td>15.4</td>
<td>5</td>
<td>11.09</td>
<td>2</td>
</tr>
<tr>
<td>Explaining the situation through heat exchange and dilution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury in the thermometer dilates along with the heat exchange and the degree of mercury ascends. The value that is measured is the temperature of the substance. (F13)</td>
<td>6</td>
<td>11.55</td>
<td>4</td>
<td>8.87</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recurring or not wrong answer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recurring explanation as to the question or reminding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is no energy exchange between the substance and the thermometer. There is a thermal balance. (E2)</td>
<td>10</td>
<td>19.2</td>
<td>15</td>
<td>33.3</td>
<td>30</td>
</tr>
<tr>
<td>The explanation provided in everyday language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suppose that we want to measure the temperature of a glass of water. We can determine the temperature by placing a thermometer in the glass. (F18)</td>
<td>4</td>
<td>7.68</td>
<td>2</td>
<td>4.44</td>
<td>15</td>
</tr>
<tr>
<td>Different Explanations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>We wait for a definite period after we have made the thermometer touch the substance. Later, it is the value that is observed in the thermometer. (F9, F29)</td>
<td>1</td>
<td>1.92</td>
<td>2</td>
<td>4.44</td>
<td>10</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrong answer (Scientific Errors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanations as to the characteristics of mercury</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury in the thermometer is becoming warm and dilating. As soon as it is a high density. On this account, mercury has been preferred. (F3)</td>
<td>1</td>
<td>1.9</td>
<td>4</td>
<td>8.88</td>
<td>8</td>
</tr>
<tr>
<td>As the mercury vaporises quickly, the degree of mercury changes quickly along with the ascended or descended temperature. So, we can measure the temperature. (K10)</td>
<td>1</td>
<td>1.9</td>
<td>1</td>
<td>2.22</td>
<td>3</td>
</tr>
<tr>
<td>Explanations in which heat is considered as a substance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is measured through the dilution of temperature which is given and taken when we make the thermometer touch the substance (F13)</td>
<td>2</td>
<td>3.8</td>
<td>5</td>
<td>11.1</td>
<td>11</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not coded/Unanswered/ Irrelevant answers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrelevant Explanations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>We read the thermometer according to the substance (solid, liquid or gas) whose temperature we measure. (F39)</td>
<td>5</td>
<td>9.64</td>
<td>7</td>
<td>15.5</td>
<td>57</td>
</tr>
<tr>
<td>The temperatures that we have taken and the characteristics of the liquid we used of the thermometer are very important. That’s to say, we can measure the temperature of other substances by referring to the boiling and freezing temperatures of the liquid. (F19)</td>
<td>1</td>
<td>1.92</td>
<td>2</td>
<td>4.44</td>
<td>8</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When the findings on the first question are examined, it is seen that the percentage of prospective physics teachers’ correct and partially correct answers to the question were a higher percentage than chemistry and biology teachers. Almost half of the prospective physics teachers (51.3%) gave wrong, irrelevant or not coded answers or left the question in the blank.

Most of the answers were from the categories of partially correct answers or recurring/ not wrong answers. It demonstrates that prospective teachers do not know exactly how thermometers to use in our daily lives to measure the temperature. 13.5 percent of prospective physics teachers, 20.0 percent of prospective chemistry teachers and 43.9 percent of prospective biology teachers gave not coded/irrelevant answers or left the question in the blank.

Findings and interpretations related to the First Law of Thermodynamics

Findings and interpretations in the second, third, fourth, fifth and sixth questions related the first law of thermodynamics are given in this section.

Second question in the test

The answers of prospective teachers to the second question “Suppose that a car suddenly breaks and stops. Then what happens to the energy of the car?” are presented in Table 4. The answer types are correct answered, correct reason; correct answer, partially correct reason; wrong answer, correct reason; wrong answer, partially correct reason; correct answer, wrong reason; wrong answer, wrong reason.

When the findings on the second question are examined, it is seen that many of the prospective teachers know because of the energy conservation, energy must be transferred to the other energy types. But a very few number of prospective teachers who commented the amount of energy transformed into heat energy due to friction.

Wrong answer, wrong reason categories examined, especially the vast majority of biology teachers’ responses (81.04%) is taken into this category. Subcategories examined, the “potential energy increases while kinetic energy decreases” observed that quite a lot of the answers given in this form. When teachers’ explanations are examined, energy conversation is described only with the kinetic energy and the potential energy.

Third question on the test

The answers of prospective teachers to the third question “Total energy is constant in the universe” what does this sentence mean to you? Explain” are presented in Table 5.
Table 4. Findings on the second question

<table>
<thead>
<tr>
<th>Answer Type</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct answer, correct reason</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>✗ Explaining the situation through friction, energy transformation and thermal energy</td>
<td>11</td>
<td>21.2</td>
<td>4</td>
</tr>
<tr>
<td>The kinetic energy of the car decreases through the friction force and it changes in thermal energy. The energy of the car decreases. (F20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct answer, partially correct reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Just explaining the effect of friction force</td>
<td>5</td>
<td>9.6</td>
<td>4</td>
</tr>
<tr>
<td>Energy dissipation occurs due to friction. (F0, F15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Explaining the situation through energy transformation and friction force</td>
<td>2</td>
<td>3.86</td>
<td>3</td>
</tr>
<tr>
<td>The kinetic energy of the car decreases through the friction force (B53)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>7</td>
<td>13.5</td>
<td>7</td>
</tr>
<tr>
<td>Wrong answer, correct reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ An explanation which claims that total energy is kept firm but that it undergoes a transformation into thermal energy through friction</td>
<td>5</td>
<td>9.6</td>
<td>5</td>
</tr>
<tr>
<td>There is no change. The energy doesn’t change according to the first law. The kinetic energy transforms into temperature through friction. (B10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrong answer, partially correct reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Explanation in which energy transformation is partially expressed.</td>
<td>6</td>
<td>11.6</td>
<td>3</td>
</tr>
<tr>
<td>There is no change. Energy is always kept. It doesn’t disappear. It changes into another type of energy. (F8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Just explaining the effect of friction force</td>
<td>5</td>
<td>9.63</td>
<td>3</td>
</tr>
<tr>
<td>There is no change. The kinetic energy decreases through friction. (K6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>11</td>
<td>21.2</td>
<td>6</td>
</tr>
<tr>
<td>Correct Answer, wrong reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Explanations in which only one type of energy is considered</td>
<td>13</td>
<td>24.98</td>
<td>12</td>
</tr>
<tr>
<td>It decreases. $E_t = \frac{1}{2}mv^2$, $v=0 \Rightarrow$ The energy becomes zero. (B57)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrong answer, wrong reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Explanations which claim that potential energy increases while kinetic energy decreases</td>
<td>5</td>
<td>9.61</td>
<td>9</td>
</tr>
<tr>
<td>There is no change. Due to the conversation of energy, the kinetic energy of the car decreases while its potential energy. As a result, total energy does not change. (B43)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✗ Explanations which claim that the energy of an immobile car increases</td>
<td>2</td>
<td>4.44</td>
<td>10</td>
</tr>
<tr>
<td>It increases. Energy increases when a car suddenly stops. (B38) There is no change. The kinetic energy of the car at the beginning and the energy it gains by stopping are equal to each other. (B51)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>5</td>
<td>9.61</td>
<td>11</td>
</tr>
</tbody>
</table>
Table 5. Findings on the third question

<table>
<thead>
<tr>
<th>Correct Answer</th>
<th>Department</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td>Explanations which claims that total energy remains stable due to energy transformations</td>
<td>30</td>
<td>57.7</td>
<td>23</td>
<td>51.1</td>
</tr>
<tr>
<td>Partially Correct Answer</td>
<td>10</td>
<td>19.2</td>
<td>13</td>
<td>28.9</td>
</tr>
<tr>
<td>Recurring or not wrong answer</td>
<td>4</td>
<td>7.68</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>Explanations which claim that total energy is stable</td>
<td>1</td>
<td>2.4</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5</td>
<td>9.6</td>
<td>2</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Wrong answer (Scientific Errors)

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Department</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanations which include energy production or consumption</td>
<td>5</td>
<td>9.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Explanations in which energy and entropy are confused with each other</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5</td>
<td>9.6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Not coded/Unanswered/ Irrelevant answers

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Department</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>It means thermodynamic and chemistry courses (K13)</td>
<td>2</td>
<td>3.8</td>
<td>7</td>
<td>15.6</td>
</tr>
</tbody>
</table>

When the findings on the third question are examined, the percentage of correct answers given to this question is higher than other questions. 57.7 percent of prospective physics teachers and 45.9 percent of prospective biology teachers gave correct answers.

Fourth question in the test

The answers of prospective teachers to the fourth question “A wise man thinks like this: “After obtaining electrical energy from water mill, it can be again to drive a pump that would lift the fallen water back to the top of the millrace. The same water would be recycled again and again. In this way, we could produce perpetual energy.” Is it possible to obtain perpetual motion/energy machines? Why or why not?” are presented in Table 6.
Table 6. Findings on the fourth question

<table>
<thead>
<tr>
<th>Correct Answer, correct reason</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Physics Education</td>
</tr>
<tr>
<td>$f$</td>
<td>$%$</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>An explanation which includes the effects of friction and efficiency. <em>Energy dissipation depends on the friction and efficiency of the motor. (F38)</em></td>
<td>15</td>
</tr>
<tr>
<td>Correct Answer, partially correct reason</td>
<td></td>
</tr>
<tr>
<td>Explanations as to efficiency</td>
<td>3</td>
</tr>
<tr>
<td>$100%$ efficiency is impossible (F8)</td>
<td></td>
</tr>
<tr>
<td>There is no system that works at $100%$ efficiency (F34)</td>
<td></td>
</tr>
<tr>
<td>Explanations as to friction</td>
<td>1</td>
</tr>
<tr>
<td>Friction does not let the generation of such an ideal system (F52)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>4</td>
</tr>
<tr>
<td>Wrong answer, correct reason</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Wrong answer, partially correct reason</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Correct Answer, wrong reason</td>
<td></td>
</tr>
<tr>
<td>Explanations in which vaporization of water is shown as a reason. <em>We cannot pump the water if it vaporizes. (B35)</em></td>
<td>10</td>
</tr>
<tr>
<td>Wrong answer, wrong reason</td>
<td></td>
</tr>
<tr>
<td>Explanations which claim that energy remains stable in all conditions. <em>Yes. Because energy does not disappear. (K7)</em></td>
<td>8</td>
</tr>
<tr>
<td>Yes. There is a continuous conversation of energy. (B94)</td>
<td></td>
</tr>
<tr>
<td>Explanations which claim that the system will work as long as water runs</td>
<td>15</td>
</tr>
<tr>
<td>Yes. The mill goes round as the water has certain flow rate. (B30)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>23</td>
</tr>
</tbody>
</table>
According to the laws of thermodynamics a system can’t work forever. Energy losses would be absolutely. Prospective teachers’ explanations are examined; the vast majority of the answers is advocating such a system would work forever. Besides, higher percentages of prospective biology teachers give the wrong answer (91.88%). This lack of information about prospective teachers on indication of the first law of thermodynamics.

Fifth question in the test

The answers of prospective teachers to the fifth question “The purpose of a petroleum (gasoline or diesel) car engine is to convert petroleum into motion so that your car can move. Is it possible to all acquired energy from the burning fuel to use to just move the car (including execution)?” are presented in Table 7.

In this question, first law of thermodynamics was asked in a different situation. Very similar to the distribution of categories of response to the fourth question. Because here, the correct answer-wrong reason and wrong answer-wrong reason of the answers given category, the percentage is higher compared to other categories.

When the findings on the fifth question are examined, it is seen that prospective teachers still ignore the energy losses. They are saying that the energy can be used entirely. This situation is not possible according to the laws of thermodynamics. The prospective teachers are trying to respond to this situation by interpreting the energy conversation. But here, the energy obtained from energy conservation due to various reasons like friction, such as heat energy can turn into various energies have been neglected.

Sixth question in the test

The answers of prospective teachers to the sixth question “For what purpose is double-glazed windows used for? Explain” are presented in Table 8.

When the findings on the sixth question are examined, it is seen that most of the prospective teachers know the why double-glazed windows are used. Heat or noise insulation used in accordance with the number of prospective teachers who are the majority. But, both heat and sound insulation less use by teachers. Thermal insulation of more explained.

The answers examined, it is seen that the prospective teachers were difficult to explain how this isolation by the laws of thermodynamics is provided. “Energy conservation” the phrase using the number of prospective teachers is quite low. In addition, there are prospective teachers who claim that there is no air between two glass double glazed windows. Therefore they believe that the insulation is provided.
Table 7. Findings on the fifth question

<table>
<thead>
<tr>
<th>Correct Answer, correct reason</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation 1: The transformation into thermal energy as a result of friction</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>Some of the energy is used for friction. Some other energies like thermal energy appear. (F38, F37)</td>
<td>22</td>
<td>42.3</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correct Answer, partially correct reason</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation 2: Energy transformation</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>The motor becomes warm. Energy cannot entirely be used. Some transformations occur. (K39)</td>
<td>3</td>
<td>5.78</td>
<td>8</td>
</tr>
</tbody>
</table>

| Explanation 3: Efficiency claim | f   | %    | f  | %   | f  | %   |
|--------------------------------|-------------------|-------------------|-------------------|
| The car cannot reach 100% efficiency. (K90) | 4   | 7.71 | 3  | 6.65 | 10 | 6.73 |

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>13.5</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wrong answer, correct reason</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wrong answer, partially correct reason</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correct Answer, wrong reason</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation 4: Wrong energy transformation</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>No. Ignition is the first thing that launches the vehicles especially with petrol. Electrical energy is also needed. (B40) First, it is transformed into thermal energy and then to kinetic. B12) If such things as air-conditioner are used, some of the energy will be used for these. (K43)</td>
<td>3</td>
<td>5.76</td>
<td>4</td>
</tr>
</tbody>
</table>

| Explanation 5: Working principle of a car | f   | %    | f  | %   | f  | %   |
|-------------------------------------------|-------------------|-------------------|-------------------|
| There is a working principle of the car. It moves as long as an impulse force work (B35) | 1   | 1.92 | 4  | 8.88 | 13 | 8.78 |

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7.68</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wrong answer, wrong reason</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation 6: Working principle of a car</td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>The working principle of a car makes the fuel being used. (K18)</td>
<td>7</td>
<td>13.45</td>
<td>6</td>
</tr>
</tbody>
</table>

| Explanation 7: No dissipation of energy will occur | f   | %    | f  | %   | f  | %   |
|----------------------------------------------------|-------------------|-------------------|-------------------|
| The energy gained from fuel is completely used. Because there is an energy conservation. B51) | 12  | 23.0 | 18 | 39.99 | 74 | 49.98 |

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>36.45</td>
<td>24</td>
</tr>
</tbody>
</table>


WCPE 2012, Istanbul, Turkey
Table 8. Findings on the sixth question

<table>
<thead>
<tr>
<th>Answer Type</th>
<th>Physics Education</th>
<th>Chemistry Education</th>
<th>Biology Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct answer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanations which include heat and sound isolation</td>
<td>5 9.6</td>
<td>3 6.7</td>
<td>8 5.4</td>
</tr>
<tr>
<td>It is used in order to minimize the heat and energy dissipation and to provide the isolation. (F15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is used in order to provide heat and sound isolation. To conserve the air inside decreases the probability of cold air and sound (K8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially correct answer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanations which include heat isolation</td>
<td>28 53.82</td>
<td>17 37.80</td>
<td>71 47.99</td>
</tr>
<tr>
<td>It provides heat isolation. (F26)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It provides heat isolation. (F3, B6, K33)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanations which include sound isolation</td>
<td>8 15.37</td>
<td>8 17.79</td>
<td>54 36.50</td>
</tr>
<tr>
<td>It provides sound isolation. (B9, K30, K31)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>36 69.2</td>
<td>25 55.6</td>
<td>125 84.5</td>
</tr>
<tr>
<td>Recurring or not wrong answer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanations in everyday language in which the term ‘isolation’ is not placed</td>
<td>- - 3 6.7 - -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On cold days, it prevents cold air. (K27)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrong answer (Scientific Errors)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanations which claim that isolation is provided through the lack of air</td>
<td>10 19.2</td>
<td>11 24.4</td>
<td>3 2.0</td>
</tr>
<tr>
<td>The lack of air prevents heat transfer. So, isolation is provided.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not coded/Unanswered/ Irrelevant answers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It has been made in an effort to balance. (K5)</td>
<td>1 1.9</td>
<td>3 6.7</td>
<td>12 8.1</td>
</tr>
<tr>
<td>It is used for resonance. (F14)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions and Discussion

On the first question which was concerning the zeroth law of thermodynamics, prospective teachers failed to express the way thermometer measured temperature in a scientific language although they knew its function in theory. This finding indicates that the operational principle of thermometer is still a blurred concept in minds despite the widespread use of a thermometer in our daily lives and a number of physical activities ranging from primary education to college.

In the remaining five questions related to the first law of thermodynamics, prospective teachers have been asked to apply the conservation of energy principle on several cases. Prospective teachers faced difficulty in explaining the sample cases though they theoretically knew the conservation of energy. Besides, the first thing that came to the minds of an overwhelming majority of teachers was kinetic and potential energy when they were asked about energy.
A good number of prospective teachers rendered false answers to the question concerning energy conversion in a closed system and cars. This finding indicates that prospective teachers lack sufficient amount of knowledge on the operational principle of a system and/or disregard the fact that a system is never to work 100% efficiency in daily life (Tokuya, Yamamoto and Takashi, 2004).

The findings of the present research manifest that prospective teachers face difficulties in applying the laws of thermodynamics on daily events and explaining the sample cases (Tokuya, Yamamoto and Takashi, 2004). It has also been ascertained that prospective teachers possess certain misconceptions and wrong ideas (Temperature and heat are the same thing. When the temperature of any object rises, there is no energy change. Energy is composed of kinetic and potential energy alone etc.). These are given in Table 9.

**Table 9. Misconceptions and wrong ideas**

<table>
<thead>
<tr>
<th>Sentences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The zeroth Law of Thermodynamics</strong></td>
</tr>
<tr>
<td>Temperature and heat are the same thing. *</td>
</tr>
<tr>
<td>When the temperature of any object rises, there is no energy change.</td>
</tr>
<tr>
<td>Mercury used in thermometers because it is a liquid evaporates very quickly.</td>
</tr>
<tr>
<td>Thermometer insulated against temperature.</td>
</tr>
<tr>
<td>If an object in the same environment as the thermometer, you cannot measure the temperature with the thermometer.</td>
</tr>
<tr>
<td>There is no thermometer temperature. When it touches matter, so is its temperature.</td>
</tr>
<tr>
<td>Heat can be transferred from cold to hot.</td>
</tr>
<tr>
<td><strong>The First Law of Thermodynamics</strong></td>
</tr>
<tr>
<td>Moving a car has an energy. When the car is stopped, the energy of the car becomes zero.</td>
</tr>
<tr>
<td>If there was no displacement, the energy of the car doesn't change.</td>
</tr>
<tr>
<td>The potential energy decreases while the kinetic energy of the car increases.</td>
</tr>
<tr>
<td>A car stationary potential energy and the weight increases.</td>
</tr>
<tr>
<td>Energy increases due to friction and kinetic energy while the car is moving.</td>
</tr>
<tr>
<td>The car suddenly stopped, the energy increases.</td>
</tr>
<tr>
<td>The kinetic energy increases while the car stop.</td>
</tr>
<tr>
<td>Friction energy and heat energy are energy varieties.</td>
</tr>
<tr>
<td>The more energy is consumed, the more energy is produced.</td>
</tr>
<tr>
<td>Energy does not remain stable because people contribute to the energy.</td>
</tr>
<tr>
<td>Energy is composed of kinetic and potential energy alone. **</td>
</tr>
</tbody>
</table>

* It has been identified as a misconception in these studies: Harrison, Grayson & Treagust, 1999; Carlton, 2000; Eryilmaz & Suremeli, 2002; Aydogan, Gunes & Gulcictek, 2003; Baser & Cataloglu, 2005; Yesilyurt, 2006 and Paik, Cho & Go, 2007.

** It has been identified as a misconception in this study: Kaper & Goedhart, 2002.

5. Suggestions

Thermodynamics’ zeroth and first laws that involve heat-temperature and energy conservation principle actually lays the base for all the processes taking place in nature that is why simple explanations of both methods should be provided starting from primary education. While explaining these laws particular care should be paid to establish connections with daily events.

By explaining energy conservation from the events that involve energy conversions, it should be aimed so long as possible to conduct processes with the other types of energy other than kinetic and potential energy.

The pre-knowledge on thermodynamics that students hold should be identified and the points they fail to comprehend should be detected; by developing new teaching strategies a more effective thermodynamics education should be achieved.
References


The Possible Influence of Teachers’ Epistemological Beliefs on Student’s Epistemological Beliefs in College Level Physics Courses

Ramani V Pilaka, Department of Physics, SKR College, Rajahmundry, Andhra University, India
Nageswar Rao Chekuri, Institute of Excellence in Teaching and Learning, Woodbury University, Burbank, USA
Eugene Allevato, Department of Sciences, Woodbury University, Burbank, USA

Abstract

Hofer assumed an influence of teachers’ personal epistemologies on students’ personal epistemologies. Educational Model for Personal Epistemology (EMPE) proposed reciprocal influences between teachers’ and students’ personal epistemologies. Schommer-Aikins observed that some components of mathematics professors’ personal epistemologies were similar to the mathematics students’ personal epistemologies. We observed that the physics teachers’ and the students’ personal epistemologies on structure of the knowledge, nature of knowing and learning, evolving knowledge, and source of ability were similar. The current study was conducted at Rajahmundry, India. 91 students who scored 90% and above in a state conducted common public exam from about 10 institutions and 109 high school and college teachers from about 90 institutions participated in the study. A translated and English version of EBAPS survey was administered to both the students and teachers. Statistical analysis indicated interesting patterns. Results of ANOVA test on teachers’ scores indicated that the teachers had significantly higher scores on axes 2 (nature of knowing and learning), 3 (real life applicability), 5 (source of ability to learn) than the scores on Axes 1 (structure of knowledge) and 4 (evolving knowledge). Similar ANOVA test on students’ scores also gave the same result. Independent t-tests between the teachers’ and students’ scores on each axis showed no significant difference on axes 1, 2, 4, and 5. However the independent t-test showed a significant difference between the teachers’ and students’ on total epistemological scores and on axis 3. Independent t-tests showed that the total scores and the scores on Axis 1 of male students were significantly higher than those of female students. Teachers’ and students’ epistemological beliefs extracted from their answers to the individual questions in the survey showed more similarities. Furthermore context-dependency of the epistemological beliefs was also observed in the extracted beliefs.

Keywords: Epistemological beliefs, Teachers, Students, Structure of the knowledge, Nature of knowing and learning, Applicability of the knowledge, evolving knowledge, source of ability to learn.

The Possible Influence of Teachers’ Epistemological Beliefs on Student’s Epistemological Beliefs in College Level Physics Courses

Epistemology is the study of beliefs about the knowledge and knowing. The beliefs individuals hold regarding these are defined as personal epistemologies. The personal epistemologies are shaped in social and cultural contexts (Vygotsky, 1978), and can change in time. The personal epistemologies (eg. Schommer, 1990; Hofer and Pintrich, 1997) on nature of the knowledge and knowing are foundational for educational experiences and they develop in time. The developmental theories on personal epistemology describe that the personal epistemological stances/positions change (eg. Perry, 1970; Baxter Magolda, 1992; Kuhn et al., 1991, 2000, 2002) on developmental continuum over a period of time. The beliefs of the individuals may change even from one context to another context (eg. Bell et al., 2002, Hammer et al., 2002, 2004). The contextual epistemologies emphasize the importance of domain specific epistemologies. A discipline is differentiated from another discipline partly by their differences in epistemological beliefs. Domain specific epistemologies shape from general epistemologies (Hofer, 2000, Palmer et al., 2008).

Several studies show that teachers’ personal epistemologies influence learning, their understanding of the students as learners, influence their perception of content knowledge and their choice of instructional
methods, classroom tasks (Eg. Kuhn et al., 2000; Howard et al 2000; Schraw 2002; Tsai 2002, Johnston et al 2001, Hofer 2001). Students interpret these practices through their own epistemological lenses and thus the students’ personal epistemologies are influenced. Hofer (2001) assumes a one-directional influence of teachers’ personal epistemologies on students’ personal epistemologies through teachers’ choice of classroom activities and instructional methods. Epistemic change in teachers is described as gradual (Brownlee et al 2001, Tsai 2002, White 2000). Bendixen and Rule (2004) suggest that an individual’s personal epistemology influences and is influenced by (reciprocal relation) the other individuals’ epistemologies and the epistemic climate thus created. The epistemological differences in an individual’s environment may trigger a mechanism of change. The epistemic climate can occur within and outside the classrooms influencing at micro (individual), meso (institutional) and macro (societal) levels. Students’ personal epistemologies can be influenced and developed through the personal epistemologies of their peers, teachers and parents, and the epistemic climate thus created.

In mathematics, Schommer-Aikins (2008) observes some components (control and speed of learning, and the source of knowledge) of teachers’ epistemologies are similar to the students’ personal epistemologies. These observed patterns between the students’ personal epistemologies and teachers’ personal epistemologies may not be accidental. In fact the Educational Model of Personal Epistemology (EMPE) by Feucht (Haerle et al., 2008; Feucht et al., 2010) proposes reciprocal influences between the personal epistemologies of teachers and learners, epistemic instruction, epistemic knowledge representation in creating epistemic climate. The construct of epistemic climate was re-conceptualized by (Feucht, 2008; Haerle and Bendixen, 2008) by integrating more components relevant to education especially for elementary classrooms. We briefly present the EMPE model and refer the readers to the original work for more details.

**EMPE Model**

According the Education Model for Personal Epistemology (EMPE), the *epistemic climate (or classroom epistemology)* is a climate that is generated from the personal epistemologies of learners and their teachers, epistemic instruction, and epistemic knowledge representation along with the reciprocal relations among these four components for developing right beliefs about knowledge and knowing. It is a holistic and dynamic approach for developing personal epistemology of students. The model is based on empirical research and draws from several theoretical models in the field of personal epistemology, and encompasses several areas such as curriculum and instruction, educational psychology, sociology, and philosophy. Even though it is developed in the context of school situation, we believe the ideas may be applicable to college level. Our findings regarding the correlation between the students’ physics epistemic beliefs and physics teachers’ epistemic beliefs, and the similarities between the math teachers’ and students’ personal epistemologies (Schommer-Aikins 2008) may be the artifacts of the proposed model in the context of college education. The EMPE model is shown in Figure 1.

![Figure 1. EMPE model for Epistemic climate.](image-url)
The model synthesizes the work from Curriculum and instruction (Kattmann et al (1996)); and education psychology (Hofer 2001; and Bendixen and Rule 2004). The bidirectional arrows represent reciprocal relations between the four components (learners’ personal epistemologies, teachers’ personal epistemologies, epistemic instruction, and epistemic knowledge representation). Total six reciprocal influences are proposed.

We now show the analysis of the collected data to show the patterns between the teachers’ and students’ epistemologies.

**Data Collection**

The study was conducted at Rajahmundry, India. A Telugu-translated version of EBAPS survey with Telugu and English printed on the same sheets was administered to 109 teachers and 91 students, a copy of which was presented in Appendix B. The survey for 91 students was administered on July 8 2011. A government funded science talent workshop was conducted for intermediate-physics-major students who recently passed 10th grade-common examinations with a score 90% or above. The survey was administered at the beginning of the one day work shop. Out of these ninety-one, 49 were female and 42 were male students. They were from ten institutions in and within a radius of about 30 km around Rajahmundry.

The teachers also belonged to the same region in and around Rajahmundry. Out of the 109 teachers from 90 institutions who participated in the survey, 98 were in-service teachers who regularly teach 10th graders and below, and 11 teachers were in-service colleges teachers who regularly teach intermediate and under graduate students. The first time the survey was administered to forty teachers on January 3, 2009. The second time the survey was administered to sixty nine teachers on January 31, 2012. There was no duplication of the surveys.

**Analysis of the data and discussion**

In this section, we analyze the data using statistical methods to explore if any patterns exist in the students’ and teachers’ scores. Furthermore to get more insight into the personal epistemologies, we look at the teachers’ and students’ surveys to find out what statements they circled. The corresponding statements are suitably modified and presented as possible epistemic beliefs they may have held at the time of taking surveys. Off course a qualitative study with actual utterances from the subjects gives better insight into their epistemological beliefs. Nevertheless the current method (we call it semi qualitative) gives a good approximation of their epistemological beliefs as the choice of answers were multiple (instead of two choices) and the chosen response should be close to their actual beliefs. The total score and scores on each axis (40 for Axis 1; 32 for Axis 2; 16 for Axis 3; 12 for Axis 4; and 20 for Axis 5) were converted into percentage scores. The statistical and the semi qualitative analyses are presented below.

**Statistical analysis**

Box plots for teachers’ and students’ scores on the structure of the scientific knowledge (Axis 1), nature of knowing and learning (Axis 2), real-life applicability (Axis 3), evolving nature of the knowledge (Axis 4), and the sources of ability to learn (Axis 5) are shown in Figures 2.
Figure 2. Box Plot of Epistemological Beliefs for teachers (blue) and students (red)

A glimpse at Teachers’ and students’ box plots (Figures 2) gives an idea that there may be some regularity between students’ and teachers’ scores. Teachers’ and students’ scores on Axis 1 and 2; 4 and 5 look similar, and the mean scores on 2, 3 and 5 may be higher than the mean scores on Axes 1, and 4. Their scores on Axis 3 look different but the spread of the scores seem similar. A detailed statistical analysis confirms these patterns and provide evidence for more patterns, hinting that there may be a relation between the students’ and teachers’ epistemological beliefs. An independent t-test on teachers’ and students’ total (all axis total) scores indicate that there is significant difference in the teachers’ and students’ total scores with teachers’ scores being higher at a p-value of 0.003. The test statistics are presented in Appendix A, Tables 1.1 through 1.4. Higher teacher’s scores on beliefs indicate that teachers have more discipline pertinent beliefs than students do. Teacher’s total score mean 60.589 and students’ total score mean 57.098.

An independent t-test to compare the teachers’ and the students’ axis wise mean scores indicate that Teacher’s Axis 3-mean scores are significantly higher than students’ Axis 3-mean scores with p-value less than 0.001. There is no significant difference between the teachers’ and students’ mean scores on Axes 1, 2, 4 and 5. The axis wise means scores and t-test p-values are presented in Table 2, Appendix A. Axis 3- teacher’s scores contributed for the significant difference in the teachers’ and students’ total scores. In light of this analysis, the students’ and the teachers’ epistemological beliefs may be similar on Axes 1, 2, 4, and 5. Teachers’ beliefs on Axis 3 may be more pertinent to the discipline’s beliefs and different from those of students’.

An analysis of variances (ANOVA) test on teachers’ axis wise mean scores indicate that the mean scores can be categorized into two sub sets. Subset 1 being Axes 1 and 4 and subset 2 being Axis 2, 3, and 5 as shown from Tukey test in Table 3 Appendix A. Subset 2 has higher mean scores than those of on subset 1. There is no significant difference between the scores on Axes 2, 3, and 5; and no difference between the scores on Axes 1 and 4. But there is significant difference between Axes 2 & 1; 2 & 4; 3&1; 3&4; 5&1; and 5&4. The significantly high scores of teachers on Axes 2, 3, 5 compared with their scores on Axes 1,4 indicate that they have relatively pertinent beliefs on nature of knowing and learning, applicability and on source of ability than on the structure of knowledge and evolving nature of knowledge. But when compared with the experts scores (90% and above on MPEX survey) they still have poor beliefs on the nature of the knowledge and knowing.

An ANOVA test on students’ scores shows three independent subsets as shown in Table 3 from Tukey’s test. There is a statistically significant difference between the Subset 1 (Axes 1 and 4) Subset 2 (Axes 3) and Subset 3 (Axes 2 and 5). The scores on Axes 1, 4 are significantly lower than their score on Axes 2, 5. The mean score on Axes 3 is higher than on Axes 1, 4. In other words the mean scores on Axes 2, 3, and 5 are significantly higher than the scores on Axes 1, and 4, which is similar to that of teachers (the mean
scores on Axes 2,3,5 are higher than the mean scores on Axes 1, 4). In the case of students, the scores on Axes 3(application) is also lower than the scores on 2 (knowing and learning), 5(source of ability) but higher than 1(structure of knowledge) and 4(evolution). The scores of teachers and students are lower on 1(structure of knowledge) and 4(evolution).

Independent t-test to compare the means of each axis between students indicates that gender is a factor only on Axis 1 while for other axis no significant difference was observed. However, total epistemological beliefs for students show significant difference using gender as a factor with male students having higher scores. The statistics are presented in Appendix A, Tables 4.1 and 4.2.

Semi qualitative analysis

Extraction of Epistemological Beliefs from EBAPS survey questions.

To extract epistemological beliefs of students and teachers, we looked at the answers the teachers and the students selected in the surveys, categorized the questions on the five axes, and counted how many subjects chose a given answer for a given question. The data with detailed analysis is presented in Appendix A, Tables 5.1 through 5.5. The survey contained multiple choice and scenario type questions. The multiple choice questions have 5-likert scale answers ranging from strongly disagree through strongly agree and scenario questions have five (A, B, C, D, E) answers to choose. 5-likert scale is revised to 3 likert scale by combining strongly disagree (agree) and somewhat disagree (agree) into disagree (agree). The answers to the scenario questions are also suitably modified. The statements presented in the survey for questions were suitably modified to present as the possible epistemological beliefs of this group of teachers and students. An example of how the epistemological beliefs were extracted is presented here. Similar extractions performed on the other axes were presented in Appendix A.

Possible epistemological beliefs on structure of knowledge (SK).Question 2 from EBAPS survey: When it comes to understanding physics or chemistry, remembering facts isn’t very important.

The choice of answers and scores are
A (Strongly disagree) = 0, B (somewhat disagree) = 1.5, C (neutral) = 2.5, D (somewhat agree) = 3.5, E (strongly agree) = 4

The number of teachers who disagree (A+B) =73 (66.97%), neutral (C) =2 (1.83%) and agree (D+E) =34 (31.19%). Similarly the number of students who disagree (A+B) = 61(67.03%), neutral (C) = 6(6.59%), and agree (D+E) = 24 (26.37%).

Majority of the teachers (66.97%) and students (67%) disagree with the statement “When it comes to understanding physics or chemistry, remembering facts isn’t very important” implying a belief something similar to the effect:

“When it comes to understanding physics or chemistry, remembering facts is important or somewhat important.” OR “Remembering facts is somewhat important or important to understand physics or chemistry” (Teachers 67%; students 67% agree).

We label the above belief as Epistemological belief (Structure of the Knowledge) SK 1.

Such epistemological beliefs are presented here as possible personal epistemologies. When students and teachers differ on beliefs, both the statements are presented.

Epistemological belief SK 2

Scientists should spend their time in gathering information. Worrying about theories can’t really understand anything. (Teachers 56%; students 52% agree).

Epistemological belief SK 3

When a scientific theory does not make sense, you just have to accept it and move on, because not
everything in science is supposed to make sense. (Teachers 66%; students 54% agree).

Epistemological belief SK 4

When solving problems the key thing is knowing the method. Understanding the “big idea” might be helpful but may not be as important. (Teachers 52%; students 52% agree).

Epistemological belief SK 5

Formulas or Equations are really the main thing to understanding physics or chemistry. The other material is helpful to decide what equations to use in which situations. (Teachers 51% agree and 49% disagree. This is real dichotomy for teachers. Nobody (0%) is neutral; students 66% agree, 7% neutral and 27% disagree).

Epistemological belief SK 6

Teacher’s belief: Events in daily-life behave according to consistent rules. But sometimes certain events (thunderstorms) are hard to explain because they behave according to complicated or hard to apply rules or the rules are fully not known. (Teachers 70%; students 48% agree).

Students’ belief: Certain events (Thunderstorms) in daily life may not behave according to the rules. (Students 52%; teachers 30% agree).

Epistemological belief SK 7

The major formulas summarize the main concepts; they’re not really separate from the concepts. In addition, those formulas are helpful for solving problems. (Teachers 75%; students 69% agree).

Epistemological belief SK 8

A large collection of multiple choice questions covering one specific fact or concept is the best format for measuring students’ understanding in physics and chemistry. (Teachers 92%; students 80% agree).

Epistemological belief SK 9

A good science textbook should show how the material in one chapter relates to the material in other chapters, because they’re not really separate. (Teachers 68%; students 65% agree).

Epistemological belief SK 10

Things in science cannot be ambiguous. They are either correct or incorrect. (Teachers 54%; students 60% agree).

Gender difference

Statistical analysis on the gender difference revealed that male students’ epistemological beliefs were significantly better than female students’ epistemological beliefs on the structure of the knowledge (Axis 1) and on the hole. But there was no significant difference on the other axes. In Table 6, Appendix A, we present the number of male and female students who chose a particular answer for a particular question on the structure of knowledge. Total number of students was 91, number of male students was 42, and females were 49.

Possible epistemological beliefs on structure of knowledge (SK) for male and female students.

Epistemological belief SK 1

When it comes to understanding physics or chemistry, remembering facts is important. OR Remembering facts is important to understand physics or chemistry. (Males 62%; females 71% agree).

Epistemological belief SK 2

Scientists should spend their time in gathering information. Worrying about theories can’t really understand anything. (Males 40%, females 61% agree; Males 48%, females 29% disagree; males 12%, females 18% neutral).
Epistemological belief SK 3

When a scientific theory does not make sense, you just have to accept it and move on, because not everything in science is supposed to make sense. (Males 55%, females 53%).

Epistemological belief SK 4

When solving problems the key thing is knowing the method. Understanding the “big idea” might be helpful but may not be as important. (Males 38%, females 63% agree; males 50%, females 22% disagree).

Epistemological belief SK 5

Formulas or Equations are really the main thing to understanding physics or chemistry. The other material is helpful to decide what equations to use in which situations. (Males 62%, females 69% agree).

Epistemological belief SK 6

Events in daily-life behave according to consistent rules. But sometimes certain events (thunderstorms) are hard to explain because they behave according to complicated or hard to apply rules or the rules are fully not known. (Males 50%, females 47%)

Certain events (Thunderstorms) in daily life may not behave according to the rules. (Males 50%, females 53% agree).

Epistemological belief SK 7

The major formulas summarize the main concepts; they’re not really separate from the concepts. In addition, those formulas are helpful for solving problems. (Males 69%, females 69% agree).

Epistemological belief SK 8

A large collection of multiple choice questions covering one specific fact or concept is the best format for measuring females’ understanding in physics and chemistry. (Males 76%, females 82%).

Epistemological belief SK 9

A good science textbook should show how the material in one chapter relates to the material in other chapters, because they’re not really separate. (Males 67%, females 63%).

Epistemological belief SK 10

Things in science cannot be ambiguous. They are either correct or incorrect. (Males 69%, Females 53%).

Discussion

We discuss here possible explanations for the results we obtained in the analysis of the data. First we will discuss the results of the statistical analysis.

Pattern 1: Axis wise comparison (independent t-tests for Axis x Axis for teachers’ and students’) indicated that there was no significant difference between the teachers’ mean scores and students’ mean scores on Axes 1,2,4, and 5. However teachers’ mean score on Axis 3 was higher than students’ mean score on Axis 3. Pattern 2: Teachers’ mean scores on Axes 2, 3, and 5 were higher than their mean scores on Axes 1 and 4, so as for students. Of course for students the mean scores on Axes 2, 5 (subset 1) were higher than the mean score on Axis 3 (subset 2) and the mean score on Axis 3 was higher than the mean scores on Axes 1 and 4 (subset 3). But in essence the mean scores on Axes 2, 3, and 5 were higher than the mean scores on Axes 1, and 4. Pattern 3: Standard deviations of teachers’ and students’ mean scores were almost same on Axis 4 (students’-21.71 and teachers’-22.02). Since there was no statistically significant difference between the teachers’ and students’ epistemological beliefs on Axes 1,2,4, and 5, and the mean score of both the groups on Axes 2,3, and 5 were higher than the mean scores on Axes 1 and 4, for this group of teachers’ and students’ the personal epistemologies on the structure of the knowledge (Axis 1), nature of knowing and learning (Axis 2), evolving nature of the knowledge (Axis 4), and on the source of ability to learn (Axis 5) could be similar, and could be different on the real-life applicability (Axis 5).
3). Also there might be a large variance in the epistemological beliefs on evolving knowledge for both the groups. Regarding the gender difference: male students’ total mean score (59.39) was significantly higher than female students’ total mean score (55.13). Furthermore male students’ mean score on Axis 1 (50.56) was higher than female students’ mean score (45.30) on the same axis and there was no significant difference between the mean scores of the male and female students on Axes 2, 3, 4, and 5. The data of this group infer that the male students’ epistemological beliefs might be more pertinent than the female students’ beliefs on the structure of the knowledge (Axis 1), and the male and female students’ might have similar beliefs on nature of knowing and leaning (Axis 2), real-life applicability (Axis 3), evolving nature of the knowledge (Axis 4) and the source ability to learn (Axis 5). A study on the physics education under graduates (Kiong, etal 2010) at the Universiti Teknologi Malaysia revealed that the female students had more sophisticated epistemological beliefs on the structure of knowledge than the male students (Males 26, Females 42; Male mean score is 64.36, female mean score 71.31). We think the gender difference may be more of a local character depending in various factors such as the upbringing, values in the community, etc. Extracted epistemological beliefs from the surveys reveal that the majority of students’ and teachers’ beliefs for this group on Axis 1, 2, 4, and 5 most likely be the same and be different on Axis 3. There could be a large variance in the teachers’ and students’ epistemological beliefs on Axes 4.

We now discuss the Extracted epistemological Beliefs from the survey.

**Teachers vs Students**

**Structure of the knowledge (Axis 1) SK.** Majority of teachers and majority of students agree on epistemological beliefs: remembering the facts is important (SK 1), scientists should spend more time in gathering information rather than worrying about theories that can’t help us understand anything (SK 2), we have to except and move on when a theory does not make sense, because not everything is supposed to make sense (SK 3), in problem solving understanding the “big idea” is helpful but not important (SK 4), formulas summarize the main concepts and helpful for solving problems (SK 7), a large collection of multiple choice questions covering concepts is better assessing method (SK 8), concepts are not really separate. Textbooks should show inter-relations (SK 9), and things in science are either right or wrong (SK 10). The groups differ on SK 6. Majority of teachers seem to have an epistemological belief something similar to that of: events in real-life behave according to consistent rules. But sometimes it is hard to apply or the rules are fully not known while majority of students seem to have a belief similar to that of: Certain events in real-life may not behave according to the rules. (Actually students split on SK 6. 52% of the students seem to have the latter belief and 48% of the students seem to have former belief.) On SK 5 situation is little different. 51% of the teachers and 66% of students seem to agree on something similar to that of: Equations are really the main thing to understanding physics or chemistry. The other material is helpful to decide what equations to use in which situations. But 49% of the teachers seem to disagree with the afore mentioned statement. They seem to have a belief something similar to that of: Equations are not main thing to understand physics or chemistry. Teachers split almost 51-49 on SK 5. Thus the majority of both the groups agree on all beliefs except on SK 6.

Epistemological belief that are similar to the majority of members in both the groups on the structure of the knowledge are: Remembering facts is important; when theories don’t make sense, we have to accept and move on without worrying too much about theories; when solving problems understanding the “big idea” is helpful but not crucial; formulas summarize the main concepts and help solving problems; concepts are inter-related; things in science are right or wrong (dualists or dichotomous nature); and multiple choice method is better for assessing the understanding of knowledge.

Statistical analysis also showed that students’ and teachers’ epistemological beliefs on the nature of knowledge were similar.

**Nature of knowing and learning (Axis 2) NKL.** Majority of teachers and students agree on the epistemological beliefs: when things disagree with personal experiences, ignore personal experiences and accept what book says (NKL 1), students generally have sense of how well they did in the exams NKL 2), relating to personal experience help understand science better(NKL 3), clear lectures with plenty of examples help learn subject (NKL 4), putting the concepts in the individuals’ own words help learn better (NKL 5), and
reflect upon the work after solving a problem (NKL 6). It is interesting to see that both the groups seem to have a belief on one hand that relating the learning to the personal experiences (general situation), putting the concepts in the individuals’ own words, reflecting upon after solving problems help learn/construct the science knowledge better (which are qualities of building own knowledge) on the other hand they also seem to believe that clear lectures with plenty of real-life examples without students doing work on their own, when your personal experiences disagree, accept what the text book says (relating the learning to personal experiences in the context of reading the textbook) help constructing the knowledge and justify the knowledge learnt using multiple choice test is contradictory. In the general context they seem to believe: relating to the personal experiences help understand the science better. In the context of reading the text book: To learn science, even though some things disagree with personal experiences, we should ignore our experiences and focus on what book says. This is an example of context dependency (Hammer 2002). Thus majority of the members from both the groups agree on all the epistemological beliefs on the nature of knowing and learning including on the context dependency. Statistical analysis also showed that students’ and teachers’ epistemological beliefs on the nature of knowing were similar.

Real-life applicability (Axis 3) RLA. For these groups, majority of teachers’ beliefs agree with the majority of students’ beliefs on: understanding science is equally important for politicians (RLA 1) and on science explains real world events. But sometimes we cannot apply, it is because the examples or principles are complicated or we don’t know the applicable principles yet (RLA 2). Students and teachers seem to disagree on RLA 3. Teachers seem to believe that: Events in daily-life behave according to consistent rules. But sometimes certain events (thunderstorms) are hard to explain because they behave according to complicated or hard to apply rules or the rules are fully not known. Students don’t seem to agree with teachers and majority of students seem to believe: Certain events (Thunderstorms) in daily life may not behave according to the rules. (RLA 3 and SK 6 result from the same question). RLA 2 (general situation) and SK 6/RLA 3 (specific to Thunderstorm) are two different questions but result in the same belief. Students’ belief changed when it came from general to specific situation. This is another instance where the beliefs are context dependent. However majority of teachers’ epistemological beliefs were consistent when it came from general to specific situation (on RLA 2 and 3). Majority of teachers’ epistemological beliefs are better than those of students’ beliefs. Statistical analysis also showed the same i.e. teachers’ epistemological beliefs on the real life applicability are more matured than students’ beliefs.

Evolving knowledge (Axis 4) EK. The Students and teachers seem to agree on the belief: science cannot be ambiguous, things are either correct or incorrect (EK 3). Both the groups have large variation on the other two beliefs scientists cannot evaluate which scientific study is the best on controversial topics (EK 1). And majority of teachers and students disagree with Even though scientific theories that are strongly supported by experimental verification don’t change that often, but always open to arguments to improve/modify theories and experiments (EK 2). They may have belief something similar to that off: Ones the scientific theories are established and experimentally verified, there is little room for changes. While the majority of teachers and students have similar beliefs on EK 2 and 3 and there is a large variance on EK 1.

Statistical analysis reflected a large standard deviation on this axis for both the students and teachers groups and there was no significant difference on the mean scores.

Source of Knowledge to learn (Axis 5) SAL. Majority of members in both the groups in this sample agree on: studying in a better way can make a big difference when struggling in physics or chemistry (SAL 1), the people who don’t have natural ability can still learn physics or chemistry (SAL 2), and everybody can learn to think scientifically, if they really want to and given enough time (SAL 3). Although majority of teachers and students seem to have beliefs something similar to that of: when struggling, studying in a better way can make a big difference, people who don’t have natural ability can still learn physics or chemistry and everybody can learn to think scientifically. In other contexts (to be successful in science course and a physicist (SAL 4), Dr. Kay Kinoshita being smarter(SAL 5)) they were split: (On SAL 4) 37% of teachers and 41% students expressed a belief: Hard work is more important than the natural ability to succeed in science courses, 41% of teachers and 42% of students have belief: natural ability and hard work are equally important, 22% of teachers and 17% of students expressed: natural ability is more important than the hard work; (on SAL 5) 54% of teachers and 42% of students believe: without natural ability, hard work will not get you anywhere in science, 18% of...
the teachers and 26% of the students believe: you need natural ability and hard work to be smarter, 28% of
the teachers and 32% of the students believe: smarter people work harder in a proper way and natural ability
is not important. This variation may because the beliefs are context dependent.

The statistical and the semi-qualitative analysis of the data of these teachers’ and students’ groups reveal
that certain epistemological beliefs of students and teachers were similar and some were dissimilar.

**Male students vs Female students**

We compare the epistemological beliefs of male and female students on the Structure of knowledge.
Statistical analysis showed that the epistemological beliefs of male students were more matured than those
of female students on the structure of the knowledge and on the other components they were the same.

**Structure of the knowledge (Axis 1) SK.** Majority of male and female students have the same beliefs
something similar to that of: remember the facts is important (SK 1), we have to except and move on when
a theory does not make sense because not everything is supposed to make sense (SK3), Formulas are the
main thing to understand physics or chemistry. The other material is helpful to decide what formula to use
in which situation (SK5), formulas summarize the main concepts and helpful for solving problems (SK7),
a large collection of multiple choice questions covering concepts is better assessing method (SK8), As the
concepts are not really separate, the textbooks should show inter-relations (SK9), and things in science
are either right or wrong, but cannot be ambiguous (SK 10). Male students seem to have little edge over
the female students on SK 2, SK 4, and on SK 6. 48% of the male students seem to believe that theories
help understand things in science where as 61% of the female (40% of the male) students seem to believe
that scientists should spend more time in gathering information rather than worrying about the theories
(SK 2). 63% of the female students seem to believe that when solving problems key thing is knowing the
method. Understanding the “big idea” is not that important, while 50% of the male students seem to
believe that understanding “big idea” also important (SK 4). 50% of the male students seem to believe that
Events in daily-life behave according to consistent rules. But sometimes certain events (thunderstorms)
are hard to explain because they behave according to complicated or hard to apply rules or the rules
are fully not known. But 53% of the female (50% of males) students seem to believe that certain events
(Thunderstorms) in daily life may not behave according to the rules.

**Conclusions**

In this study, we performed statistical and semi-qualitative analysis on the data of 91 undergraduate
students who scored 90 and above in the public exams and 109 teachers from the surrounding institutions.
We administered the translated version of EBAPS surveys over a period of two years. The statistical
analysis showed that there was no significant difference between students’ and teachers’ epistemological
beliefs on the structure of the knowledge, nature of knowing and learning, evolving knowledge and
source ability to learn. However there was significant difference on the applicability of the knowledge.
The epistemological beliefs for both the groups on the nature of knowing and learning, applicability, and
source of ability to learn were more matured than the beliefs on the structure of the knowledge and
evolving nature of knowledge. There was a large variance in the beliefs about the evolving nature of the
knowledge. The semi-qualitative analysis also showed that the beliefs of majority of teachers and students
for these groups were the similar on the structure of the knowledge, nature of knowing and learning,
evolving nature of the knowledge and the source of ability to learn. Context dependence nature of the
epistemological beliefs was also observed on certain axes. Just as EMPE model suggested in reference to
young and adult children, we predict that there should be a reciprocal-relation between the teachers’
and students’ personal epistemologies at college level for physics and chemistry. More qualitative and
quantitative studies with more controls are needed to understand if teachers’ personal epistemologies
have reciprocal relation with the students’ personal epistemologies in physics or chemistry for college
students. As regards to the gender differences on the epistemological beliefs, we think it may differ
from culture to culture, may be different even within the same culture depending upon various factors
including the upbringing and epistemological climates. We observed that male students had matured
epistemological beliefs on the structure of knowledge than the female students while Kiong etal (2010)
observed at Universiti Teknologi, Malaysia, that female students had better epistemological beliefs on the
structure of the knowledge than the male students.
Even though the students had physics for a total of five years in high school (three years), and in intermediate (two years) colleges, and had scored 90% and above in the common intermediate exam the beliefs were poor. Possible reasons could be that the students probably hardly had time to reflect upon due to the instructional methods followed in the institutions; the school and college education in this area require the teachers to complete the syllabus at the cost of students' understanding; focus more on repetition and memorization than reflecting upon; and focus the instruction to pass the common final examinations that emphasizes on writing definitions and deriving equations. The data on the teachers' beliefs revealed that the teachers in this area may have poor epistemological beliefs. These teachers were also the product of the same educational system. It was interesting to see that the male students had better epistemological beliefs than the female students.

In view of this study we recommend that the local educational authority should conduct workshops for in service teachers on the epistemological beliefs and instructional methods, change the examination system that elicit students' holistic knowledge and emphasize on reasoning, conduct bridge courses, and restructure the high school and college syllabus to integrated syllabus.

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References


Appendix A

Table 1.1. Group Statistics. Teachers’ and students’ mean scores, std. deviation and error means

<table>
<thead>
<tr>
<th>Axes_ST</th>
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<th>Std. Deviation</th>
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Table 1.2 Descriptive statistics for teachers

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<th>Minimum</th>
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Table 1.3 Descriptive statistics for students

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Table 1.4 Independent t-test for total scores between teachers and students

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<tr>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
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<td>F</td>
<td>Sig.</td>
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<td>Equal variances assumed</td>
<td>1.287</td>
</tr>
<tr>
<td>Equal variances not assumed</td>
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Table 2. Independent t-test (Levene’s) F & p-values and epistemological beliefs mean scores.

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<tr>
<th>Axis</th>
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<th>Teachers</th>
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<th>p-value</th>
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<td>1</td>
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Table 3. Tukey’s test for both teachers and students indicating different subsets

Tukey HSD

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Means for groups in homogeneous subsets are displayed

a. Uses Harmonic Mean Sample Size = 109,000

Tukey HSDa

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Means for groups in homogeneous subsets are displayed

a. Uses Harmonic Mean Sample Size = 91,000
Table 4.1 Descriptive statistics for male and female students

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<tr>
<th>Gender</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
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Table 4.2 Independent t-test for different axis between students with gender as a factor

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Table 5.1 Number of teachers (Tchrs) and students (Stdnts) selected answers to a given question are presented in the cells. A, B, C, D and E are choice of answers. Axis 1 Structure of knowledge.

<table>
<thead>
<tr>
<th>Q.No</th>
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<th>C</th>
<th>D</th>
<th>E</th>
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Table 5.2 Number of teachers and students selected answers to questions. A, B, C, D and E are choice of answers. Axis 2 Nature of knowing and learning (NKL)

<table>
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<th>Q.No</th>
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<th>C</th>
<th>D</th>
<th>E</th>
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Possible Epistemological Beliefs On Nature Of Knowing And Learning (NKL)

Epistemological belief NKL 1

To learn science, even though some things disagree with personal experiences, we should ignore our experiences and focus on what book says. (Teachers 86%; students 85% agree).

Epistemological belief NKL 2

Students can generally have a sense of how well they did the test soon after they complete the test. (Teachers 72%; students 75% agree).

Epistemological belief NKL 3

Relating to the personal experiences help understand the science better. (Teachers 90%; students 92% agree).
Epistemological belief NKL 4

Clear lectures with plenty of real-life examples and sample problems help most good students learn physics or chemistry even without students doing sample questions and solving problems on their own. (Teachers 90%; students 77% agree).

Epistemological belief NKL 5

When learning science concepts, putting those in individuals’ own words help learn better. (Teachers 66%; students 65% agree).

Epistemological belief NKL 6

After solving a problem reflecting upon how principles applied, meaning of the solution, procedure, etc. help improve problem solving skills. (Teachers 73%; students 70% agree).

Table 5.3 Number of teachers and students selected answers to questions. A, B, C, D and E are choice of answers. Axis 3 Real-life applicability (RLA)

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Possible epistemological beliefs on Real life applicability (RLA)

Epistemological belief RLA 1

Teachers’ Belief: Understanding science is important for scientists as well as for politicians. (Teachers 78%; students 57% agree).

Epistemological belief RLA 2

Science explains/applies to real-world. But sometimes we cannot apply to some example, it is because the example or principles are very complicated or we do not know the applicable principles yet. (Teachers 82%; students 63% agree).

Epistemological belief RLA 3

Teacher’s belief: Events in daily-life behave according to consistent rules. But sometimes certain events (thunderstorms) are hard to explain because they behave according to complicated or hard to apply rules or the rules are fully not known. (Teachers 70%; students 48% agree).

Students’ belief: Certain events (Thunderstorms) in daily life may not behave according to the rules. (Students 52%; teachers 30% agree).

Table 5.4 Number of teachers and students selected answers to questions. A, B, C, D and E are choice of answers. Axis 4 Evolving knowledge (EK)

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**Possible epistemological beliefs on evolving knowledge (EK)**

Epistemological belief EK 1

*When it comes to controversial topics, there’s no way for scientists to evaluate which scientific studies are the best. Everything’s up in the air (Teachers 44% agree, 12% neutral and 44% disagree; Students 45% agree, 27% neutral, 28% disagree).*

Epistemological belief EK 2

*Even though scientific theories that are strongly supported by experimental verification don’t change that often, science accepts arguments to improve/modify theories and experiments (Teachers 16% agree, 84% don’t agree; Students 10% agree, 90% don’t agree).*

Epistemological belief EK 3:

*Things in science cannot be ambiguous. They are either correct or incorrect. (Teachers 54%; students 60% agree).*

**Table 5.5** Number of teachers and students selected answers to questions. A, B, C, D and E are choice of answers. Axis 5 Source of ability to learn (SAL)

<table>
<thead>
<tr>
<th>Q.No</th>
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<th>C</th>
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</table>

**Possible epistemological beliefs on Source of ability to learn (SAL)**

Epistemological belief SAL 1

*For those who have trouble in physics or chemistry, studying in a better way can make a big difference. (Teachers 96%; students 90% agree).*

Epistemological belief SAL 2

*The people who don’t have natural ability can still learn physics or chemistry (Teachers 84%; students 57% agree).*

Epistemological belief SAL 3

*Almost everybody could learn to think more scientifically, if they really wanted to and given enough time. (Teachers 82%; students 86% agree).*

Epistemological belief SAL 4

*Hard work is more important than the natural ability to be successful in science courses (Teachers 37%; students 41% agree).*

Natural ability and hard work are equally important. (Teachers 41%; students 42% agree).

Natural ability is more important than the hard work. (Teachers 22%; students 17% agree).

Epistemological belief SAL 5

*Some people (in the context of Kay Kinoshita, the physicist) are just smarter at science than other people. Without natural ability, hard work won’t get you anywhere in science. (Teachers 54%; students 42% agree).*

Some people are just smarter at science than other people, because they have natural ability and work hard work. (Teachers 18%; students 26% agree).
Some people are smarter in science than other people, because they work harder in a proper way. Natural ability is not important. (Teachers 28%; students 32% agree).

Table 6. Number of male and female students selected answers to questions. A, B, C, D and E are choice of answers. Axis 1 Structure of knowledge.

<table>
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EBAPS
PART-I
Directions: For each of the following items, please read the statement, and indicate on the answer sheet how strongly you agree or disagree.

<table>
<thead>
<tr>
<th>A. Strongly Disagree</th>
<th>B. Somewhat Disagree</th>
<th>C. Neutral</th>
<th>D. Somewhat Agree</th>
<th>E. Strongly Agree</th>
</tr>
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</table>

1. Sujatha just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Sujatha shouldn’t think about her own experiences; she should just focus on what the book says.

2. When it comes to understanding physics or chemistry, remembering facts isn’t very important.

3. Obviously, computer simulations can predict the behaviour of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of people, such as how many people will buy new television sets next year.

4. When it comes to science, most students either learn things quickly, or not at all.

5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.

6. When it comes to controversial topics such as which foods cause cancer, there’s no way for scientists to evaluate which scientific studies are the best. Everything’s up in the air!

7. A teacher once said, “I don’t really understand something until I teach it.” But actually, teaching doesn’t help a teacher understand the material better; it just reminds her of how much she already knows.

8. Scientists should spend almost all their time gathering information. Worrying about theories can’t really help us understand anything.

9. Someone who doesn’t have high natural ability can still learn the material well even in a hard chemistry or physics class.
10. Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.

11. When handing in a physics or chemistry test, you can generally have a sense of how well you did even before talking about it with other students.

12. When learning science, people can understand the material better if they relate it to their own ideas.

13. If physics and chemistry teachers gave really clear lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.

14. Understanding science is really important for people who design rockets, but not important for politicians.

15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the “big ideas” might be helpful for specially-written problems, but not for most regular problems.

16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.

17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

PART-II

DIRECTIONS: Multiple choice. On the answer sheet, fill in the answer that best fits your view.
(a) to (e)  అనుకున్న విషయంలో మీకు మీకు సాధారణంయే వాడబడుస్తాయి.

18. If someone is trying to learn physics, is the following a good kind of question to think about? Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?

అంతే అంటారు నాణూలను వచ్చి నేను నేను చాలా వాడారను? మరియు నేను నేను వచ్చి మచ్చి వచ్చి నేను నేను చాలా వాడారను?
I. It works, but it's not perfect.
II. It works, but it's not perfect.

a) Yes, definitely. It's one of the best kinds of questions to study.

b) Yes, to some extent. But other kinds of questions are equally good.

c) Yes, a little. This kind of question is helpful, but other kinds of questions are more helpful.

d) Not really. This kind of question isn't that great for learning the main ideas.

e) No, definitely not. This kind of question isn't helpful at all.

Scientists are having trouble predicting and explaining the behavior of thunderstorms. This could be because thunderstorms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunderstorms don't behave consistently according to any set of rules, no matter how complicated and complete that set of rules is.

a) Although things behave in accordance with rules, those rules are often complicated, hard to apply, or not fully known.

b) Some things just don't behave according to a consistent set of rules.

c) Usually it's because the rules are complicated, hard to apply, or unknown; but sometimes it's because the thing doesn't follow rules.

d) About half the time, it's because the rules are complicated, hard to apply, or unknown; and half the time, it's because the thing doesn't follow rules.

e) Usually it's because the thing doesn't follow rules; but sometimes it's because the rules are complicated, hard to apply, or unknown.

In physics and chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.

(a) to (e) don't re
card these as separable.

a) The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems.
b) The major formulas are kind of "separate" from the main concepts, since concepts are ideas, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning.

21. To be successful at most things in life...
   a) Hard work is much more important than inborn natural ability.
   b) Hard work is a little more important than natural ability.
   c) Natural ability and hard work are equally important.
   d) Natural ability is a little more important than hard work.
   e) Natural ability is much more important than hard work.

22. To be successful at science...
   a) Hard work is much more important than inborn natural ability.
   b) Hard work is a little more important than natural ability.
   c) Natural ability and hard work are equally important.
   d) Natural ability is a little more important than hard work.
   e) Natural ability is much more important than hard work.
23. Of the following test formats, which is best for measuring how well students understand the material in physics and chemistry? Please read each choice before picking one.

(a) Large (e) Small number of longer questions and problems, each of which covers several facts and concepts.

b) A small number of longer questions and problems, each of which covers several facts and concepts.

c) Compromise between (a) and (b), but leaning more towards (a).

d) Compromise between (a) and (b), favoring both equally.

e) Compromise between (a) and (b), but leaning more towards (b).

PART-III

DIRECTIONS: In each of the following items, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other.

24. Rohit: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit", because they're not really separate.

Suresh: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before choosing one.

(a) Large (e) Small number of longer questions and problems.

b) Although I agree more with Rohit, I think Suresh makes some good points.

c) I agree (or disagree) equally with Suresh and Rohit.

d) Although I agree more with Suresh, I think Rohit makes some good points.

e) I agree almost entirely with Suresh.
25. Divya: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.

Gita: May be she is. But when it comes to being good at science, hard work is more important than "natural ability". I bet Dr. Kinoshita does well because she has worked really hard.

Divya: Well, may be she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!

a) I agree almost entirely with Divya.

b) Although I agree more with Divya, I think Gita makes some good points.

c) I agree (or disagree) equally with Divya and Gita.

d) Although I agree more with Gita, I think Divya makes some good points.

e) I agree almost entirely with Gita.

26. Kartik: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me.

Ganesh: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.

a) I agree almost entirely with Kartik.

b) Although I agree more with Kartik, I think Ganesh makes some good points.

c) I agree (or disagree) equally with Kartik and Ganesh.

d) Although I agree more with Ganesh, I think Kartik makes some good points.

e) I agree almost entirely with Ganesh.
27. Kamala: I like the way science explains things I see in the real world.

Sita: I know that’s what we’re “supposed” to think, and it’s true for many things. But let’s face it, the science that explains things we do in lab at school can’t really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.

Kamala: I still think science applies to almost all real-world experiences. If we can’t figure out how, it’s because the stuff is very complicated, or because we don’t know enough science yet.

a) I agree almost entirely with Kamala.

b) I agree more with Kamala, but I think Sita makes some good points.

c) I agree (or disagree) equally with Sita and Kamala.

d) I agree more with Sita, but I think Kamala makes some good points.

e) I agree almost entirely with Sita.

28. Swetha: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can’t the scientists agree?

Purnima: May be the evidence supports both theories. There’s often more than one way to interpret the facts. So we have to figure out what the facts mean.

Swetha: I’m not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts speak for themselves.

a) I agree almost entirely with Swetha.

b) I agree more with Swetha, but I think Purnima makes some good points.

c) I agree (or disagree) equally with Purnima and Swetha.
d) I agree more with Purnima, but I think Swetha makes some good points.

29. Lalitha: In my opinion, science is a little like fashion; something that’s “in” one year can be “out” the next. Scientists regularly change their theories back and forth.

Rajani: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There’s little room for argument.

a) I agree almost entirely with Lalitha.

b) Although I agree more with Lalitha, but I think Rajani makes some good points.

c) I agree (or disagree) equally with Rajani and Lalitha.

d) Although I agree more with Rajani, but I think Lalitha makes some good points.

e) I agree almost entirely with Rajani.

0. Padma and Aruna are working on a homework assignment together...

Padma: O.K., we just got problem #1. I think we should go on to problem #2.

Aruna: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.

Padma: Aruna, we know it’s the right answer from the back of the book, so what are you worried about? If we didn’t understand it, we wouldn’t have gotten the right answer.

Aruna: No, I think it’s possible to get the right answer without really understanding what it means.

a) I agree almost entirely with Padma.

b) I agree more with Padma, but I think Aruna makes some good points.

c) I agree (or disagree) equally with Aruna and Padma.

d) I agree more with Aruna, but I think Padma makes some good points.

e) I agree almost entirely with Aruna.
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Physics Students’ Epistemological Beliefs and Their Conceptual Change

Feral Ogan-Bekiroglu and Ercan Kaymak, Marmara University, Istanbul, TURKEY

Abstract

In recognition of the presuppositions mentioned in the literature, it is important for teachers and educators to identify students’ epistemological beliefs and to examine their link to learning. Therefore, the purposes of this study were to determine high school students’ epistemological beliefs and to examine any relationship between their beliefs and their conceptual change in physics. Theoretical framework of this study is based on the conceptual change model. Correlational study design with quantitative and qualitative methods was used for the research. The high school students’ epistemological beliefs were determined by using Schommer’s Epistemological Beliefs Inventory. Assessment Instrument for the Concepts of Work, Power, and Energy was developed to assess the students’ conceptual change. The following conclusions can be drawn from the study. First, high school students’ epistemological beliefs are very close to sophistication. Second, students have more sophisticated beliefs about the acquisition of knowledge while they have less sophisticated beliefs about the nature of knowledge. Third, there is no relationship between students’ general epistemological beliefs and their conceptual change in physics.

Introduction and Purposes of the Study

The role of epistemological beliefs is likely to be subtle, yet ubiquitous because these beliefs are likely to influence how students learn, how teachers instruct, and subsequently, how teachers knowingly or unknowingly modify students’ epistemological beliefs (Schommer-Aikins, 2004). Therefore, students’ epistemological beliefs have come into prominence. Although research on epistemological beliefs has expanded and intensified considerably over the past two decades, there are still some issues that need to be explored. One controversial discussion, for example, is whether epistemological beliefs are related to learning. The purposes of this study were to determine high school students’ general epistemological beliefs and to explore any relationship between their beliefs and their conceptual change in physics.

Theoretical Framework

Theoretical framework of this study is based on the conceptual change model (or CCM) developed by Posner, Strike, Hewson, and Gertzog (1982). According to this model, learning involves an interaction between new and existing conceptions with the outcome being dependent on the nature of the interaction. There are two major components to the CCM (Hewson, 1992). The first of these components is the conditions that need to be met (or no longer met) with the status of a person’s conception in order for a person to experience conceptual change. The second component is the person’s conceptual ecology (following Toulmin, 1972) described as the existing interrelated networks of concepts that influence the selection of a new concept playing a central and organizing role in thought. Several elements of conceptual ecology are identified as anomalies, analogies, metaphors, epistemological beliefs, metaphysical beliefs, knowledge from other areas of inquiry, and knowledge of competing conceptions. Therefore, personal epistemological beliefs, namely, beliefs about the nature of knowledge and acquisition of knowledge were considered as playing an important role in learning.

Researchers and educators identified various theoretical presuppositions about the importance of epistemological beliefs and their relation to learning. Pintrich, Marx and Boyle (1993) state that beliefs play a crucial role in how students approach and process information. Among these, epistemological beliefs are considered as playing a significant role (Stathopoulou & Vosniadou, 2007). Students’ epistemological beliefs may either enhance or constrain the scope and nature of the motivational beliefs, learning strategies, and knowledge that are accessible to the learner as well as the nature and quality of various learning outcomes (Paulsen & Wells, 1998). In other words, epistemological beliefs may act as resources facilitating conceptual change and guide students to intentionally pursue the goal of knowledge revision.
(Mason, 2002). They can influence both the kinds of new information that is picked up from the physical and sociocultural context and the way in which this information is interpreted (Stathopoulou & Vosniadou, 2007). Epistemological beliefs have a critical place in the classroom because these beliefs may help or hinder learning (Schommer & Walker, 1995). Consequently, the research on epistemological beliefs helps us understand how individuals resolve competing knowledge claims, evaluate new information, and make fundamental decisions that affect their lives and the lives of others (Hofer, 2001). Epistemological beliefs may also affect the ways that students evaluate their learning (May & Etkina, 2002). In recognition of the presuppositions mentioned above, it is important for teachers and educators to identify students’ epistemological beliefs and to examine their link to learning.

### Literature Review on Epistemological Beliefs

Epistemological research was first influenced by Perry’s (1968) work, who concluded that students’ beliefs about knowledge evolved through their college years. Muis (2004) stated that Piaget’s consideration of genetic epistemology was another cornerstone of research on personal epistemology. While some researchers focused on beliefs and their relation to knowledge construction (Braten & Stromso, 2004; Mason, 2002; Qian & Alvermann, 1995; Schommer, 1990; Sinatra & Pintrich, 2003; Stathopoulou & Vosniadou, 2007), some highlighted demographic and background factors in epistemological beliefs (Hofer, 2001; Paulsen & Wells, 1998; Walkera, Brownleea, Lennoxa, Exleya, Howellsb & Cocker, 2009). There also has been an interest in the changes that occur in individuals’ epistemological beliefs over time (Buehl & Alexander, 2001; Ogan-Bekiroglu & Sengul-Turgut, 2011, Schommer, 1993; Schommer, Calvert, Gariglietti & Bajaj, 1997).

Schommer (1990) conducted her research in a midwestern city with 117 junior college students and 149 university students to find an answer for the following question: “How do beliefs about the nature of knowledge affect comprehension?”. She suggested that epistemological beliefs seemed to affect students’ processing of information and monitoring formation. Additionally, belief in quick learning appeared to affect the degree to which students integrate knowledge (Schommer, 1990).

Qian and Alvermann (1995) carried out canonical correlation analyses to explore the relationship between epistemological beliefs and conceptual change learning (CCL) by using Schommer’s questionnaire. Their participants were 212 students in Grades 9-12 at a high school in Georgia. They showed that beliefs about Simple-Certain Knowledge contributed the most to CCL whereas beliefs about Innate Ability contributed the least. The authors found that epistemological beliefs predicted conceptual change and beliefs about simple-certain knowledge and quick learning were important factors in CCL.

Windschitl and Andre (1998) investigated the effects of a constructivist versus objectivist learning environment on college students’ conceptual change by taking the students’ epistemological beliefs into account. They used Schommer’s questionnaire. Their results indicated that students with less advanced beliefs about nature and acquisition of knowledge reached higher results in the traditional setting while students with more sophisticated beliefs performed better in the innovative setting.

Braten and Stromso (2004) examined the relative contribution of epistemological beliefs to the adoption of mastery, performance-approach, and performance-avoidance goals by working with 80 Norwegian student teachers with the help of quantitative research methods. They found that epistemological beliefs about the speed of knowledge acquisition predicted achievement goals. That is, students who believed that learning occurs quickly or not at all were less likely to adopt mastery goals and more likely to adopt performance-approach and performance-avoidance goals. In addition, students who believed in stable and given knowledge were less likely to adopt mastery goals (Braten & Stromso, 2004).

Results of this study would add to the literature by determining high school students’ epistemological beliefs and examining the relationship between their epistemological beliefs and conceptual change.
**Methodology**

Correlational study design with quantitative and qualitative methods was used for the research.

**Participants and Setting**

The research was conducted with 18 tenth-grade students studying in an urban school. Their average age was 16. The population of girls was little higher (10 females). Data were collected in their physics class.

**Inventories**

The students’ general epistemological beliefs were determined by using Schommer’s Epistemological Beliefs Inventory (EBI) that she developed in 1990. This inventory consisted of 63 items with five-Likert-type scale distributed under four dimensions. These dimensions were simple knowledge and certain knowledge- naïve beliefs about the nature of knowledge- and innate ability and quick learning- naïve beliefs about the acquisition of knowledge (Schommer, 1990). Belief in Simple Knowledge ranges from the belief that knowledge is characterized as isolated bits and pieces to the belief that knowledge is characterized as interrelated concepts. Belief in Certain Knowledge ranges from the belief that knowledge is absolute to the belief that knowledge is tentative. Belief in Innate Ability ranges from the belief that the ability to learn is fixed at birth to the belief that the ability to learn can be improved over time. Belief in Quick Learning ranges from the belief that learning is quick or not at all to the belief that learning is gradual. According to Schommer, epistemological beliefs are reconceived as a system of more or less independent beliefs.

The second instrument was Assessment Instrument for the Concepts of Work, Power, and Energy (AIWPE) developed by the authors to assess students’ conceptual change. The concepts of work, energy and power exist in the elementary science curriculum. Therefore, the students had prior knowledge of these concepts. The development procedure of the AIWPE was as follows: After common misconceptions of the concepts of work, power, and energy were discovered by reviewing the literature, interviews about students’ difficulties on these concepts were done by the second author with four physics teachers. Then, the authors created open-ended questions of the instrument based on the data gathered from the literature review and interviews. The authors ensured content validity of the instrument and face validity of the questions by working together with the experts i.e. two physics educators and one physics teacher. At last, the inventory was pilot tested with a group of tenth graders and the final document was got ready.

The AIWPE consisted of 13 open-ended questions measuring conceptual and procedural knowledge (Author 2, 2010). Each question was worth five points; thus, the highest score that someone could get from the instrument was 65. The measured concepts and Bloom’s Taxonomy level for each question are given in Table 1. In the AIWPE, one question was in knowledge level, four questions were in comprehension level, three questions were in application level and five questions were in analysis level.

<table>
<thead>
<tr>
<th>Question</th>
<th>Measured Concepts</th>
<th>Bloom’s Taxonomy Level</th>
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<tbody>
<tr>
<td>1</td>
<td>Work</td>
<td>Comprehension</td>
</tr>
<tr>
<td>2</td>
<td>Power and force</td>
<td>Comprehension</td>
</tr>
<tr>
<td>3</td>
<td>Work</td>
<td>Comprehension</td>
</tr>
<tr>
<td>4</td>
<td>Potential energy, conservation of energy</td>
<td>Application</td>
</tr>
<tr>
<td>5</td>
<td>Potential and kinetic energy</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Transformation of energy</td>
<td>Comprehension</td>
</tr>
<tr>
<td>7</td>
<td>Transformation of energy</td>
<td>Application</td>
</tr>
<tr>
<td>8</td>
<td>Work</td>
<td>Analysis</td>
</tr>
<tr>
<td>9</td>
<td>Work-energy relation</td>
<td>Analysis</td>
</tr>
<tr>
<td>10</td>
<td>Power</td>
<td>Analysis</td>
</tr>
<tr>
<td>11</td>
<td>Potential energy, reference point</td>
<td>Knowledge</td>
</tr>
<tr>
<td>12</td>
<td>Transformation of energy</td>
<td>Analysis</td>
</tr>
<tr>
<td>13</td>
<td>Variables of potential and kinetic energy, conservation of energy</td>
<td>Analysis</td>
</tr>
</tbody>
</table>
In addition to the measurements mentioned above, one of the authors observed the participants throughout the research and completed the rating scale prepared to know the students better.

Examples from the observer rating scale are as follows (Author 2, 2010):

*Observer Rating Scale* ((1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always)

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<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tr>
<td>S/He prefers to be silent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>S/He takes notes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/He does not listen to the teacher</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/He asks relevant questions</td>
<td></td>
<td></td>
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</table>

*Data Collection*

The participants were answered to the EBI in the beginning of the research. Next week, their knowledge about work, power and energy concepts was assessed in the pre-test before the instruction started. The instruction lasted six weeks. Finally, they gave their responses to the questions in the inventory one more time in the post-test.

The students’ knowledge of work, power and energy concepts was assessed in the pre-test before the instruction started. They gave their responses to the questions in the AIWPE one more time in the post-test.

*Data Analysis*

Data for the participants’ epistemological beliefs were analyzed quantitatively. The students’ epistemological beliefs were categorized as low (1.0 – 2.0), medium (2.01 – 3.0), high (3.01 – 4.0), and very high (4.01 – 5.0) for each dimension because beliefs are held in clusters.

Data for the participants’ conceptual change were analyzed qualitatively. The students’ knowledge for each question was categorized as compatible elaborate, compatible sketchy, compatible-incompatible, incompatible sketchy, incompatible elaborate, and no response based on the bidimensional coding offered by Hogan and Fisherkeller (1996). Based on this scale, participants’ response concurring with the scientific proposition and having sufficient detail to show the thinking behind them was coded as “compatible elaborate”. However, if the essential details were missing, it was coded as “compatible sketchy”. Participants’ response disagreeing with the scientific proposition and having details or coherent logic was coded as “incompatible elaborate”. Nevertheless, if very little detail or logic was given in the response, it was coded as “incompatible sketchy”. If the participant made sketchy statements concurring with the scientific proposition and s/he also made sketchy statements disagreeing with the scientific proposition, his/her knowledge was coded as “compatible/incompatible”. If there was no response, it was coded as “no response”.

For example, the third question in the AIWPE was as follows: Does the Earth do work on its satellite? The following response was coded as compatible elaborate: “The gravitational force on the satellite acts toward the Earth as a centripetal force, inward along the radius of the satellite’s orbit. The satellite’s displacement at any moment is along the circle, in the direction of its velocity, perpendicular to the radius and perpendicular to the force of gravity. Hence, the angle between the force and the instantaneous displacement of the satellite is 90°. Therefore, the work done by gravity is zero”.

Since some of the questions required doing calculations and application of formulas, the students’ knowledge levels were coded based on the percentage of the correct solution. Consequently, if the participant could solve up to 20% of the question scientifically, his/her response was coded as incompatible elaborate. On the other hand, if the participant could find 81% to 100% scientific solution for the question, his/her knowledge for that question was coded as compatible elaborate. Table 2 shows this coding scheme in detail.
Table 2. Coding scheme for the questions requiring calculations

<table>
<thead>
<tr>
<th>Percentage of the correct solution</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Incompatible elaborate</td>
</tr>
<tr>
<td>21-40</td>
<td>Incompatible sketchy</td>
</tr>
<tr>
<td>41-60</td>
<td>Compatible/Incompatible</td>
</tr>
<tr>
<td>61-80</td>
<td>Compatible sketchy</td>
</tr>
<tr>
<td>81-100</td>
<td>Compatible elaborate</td>
</tr>
</tbody>
</table>

One of the authors categorized the participants’ physics knowledge. The other author randomly selected 20% of the students and categorized their knowledge. Then, both authors compared their categorizations and reached 91% of agreement. The reliability measured by Cohen's κ was 0.85. There seems to be general agreement that Cohen’s κ value should be at least 0.60 or 0.70 (Wood, 2007). Consequently, the categorization done for the participants’ knowledge had reliability. The authors re-categorized the knowledge codes that they could not have agreement on and final categorization was constructed by reaching consensus. Finally, the second author revised all the students’ knowledge categories. In order to determine if the change between pre-test and post-test was significant, paired samples t-tests were performed.

Results and Discussion

The students’ epistemological beliefs in four dimensions and their knowledge levels before and after the instruction are presented in Table 3. In general, while most of the students (83%) had high-level epistemological beliefs, only 11% of them held medium-level beliefs. This result is compatible with Yang’s (2005) finding that most students were multiplist i.e. the second highest belief level.

Table 3. The students epistemological beliefs and their conceptual knowledge

<table>
<thead>
<tr>
<th>S.</th>
<th>Innate Ability</th>
<th>Simple Knowledge</th>
<th>Quick Learning</th>
<th>Certain Knowledge</th>
<th>Overall Beliefs</th>
<th>Pre-Test</th>
<th>Post-Test</th>
<th>Conceptual Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>M</td>
<td>H</td>
<td>VH</td>
<td>H</td>
<td>IS</td>
<td>CS</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>M</td>
<td>CI</td>
<td>CS</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>VH</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>CI</td>
<td>CS</td>
<td>+</td>
</tr>
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S: Students, L: Low, M: Medium, H: High, VH: Very High, IS: Incompatible Sketchy, CI: Compatible Incompatible, CS: Compatible Sketchy, CE: Compatible Elaborate, +: Conceptual Gain between pre- and post-tests, /: No conceptual difference between pre- and post-tests
In the dimension of innate ability, 12% of the students had very-high-level beliefs whereas 88% of them had high-level beliefs. There was growing realization among the students that ability to learn was not fixed and might be developed. Regarding the simplicity of knowledge dimension, on the other hand, more than a half of the students’ (56%) held medium-level epistemological beliefs and 44% of them were able to reach high-level in terms of their beliefs. That is, more than a half of the students started to believe that knowledge was not simple. With regards to the quick learning dimension, again 12% of the students had very-high-level beliefs while 88% of them had high-level beliefs. This means that there was growing realization among individuals that one could not learn quickly, learning might be a developmental process and there was a possibility that someone learn in time. There was diversity in the certainty of knowledge dimension. Put differently, 5% of the students had low-level beliefs, a half of the students had medium-level beliefs, and 33% of them held high-level beliefs. There was beginning of the recognition of diversity and uncertainty of knowledge among the half of the students. These findings demonstrate that the students had quite sophisticated beliefs in the dimensions of innate ability and quick learning. That is, more than a half of the students started to believe that knowledge was composed of interrelated concepts and could change over time.

Results of the paired samples t-tests illustrated that the students showed significantly higher performance in the post-test than they showed in the pre-test (MPre–Post = -1.08), t (16) = -7.69, p < 0.001. There was no correlation between two tests (r = 0.12, p = 0.648). That is, it is not possible to say that the students whose scores were high in the pre-test had high scores in the post-test. Table 3 illustrates that while 17% of the students did not change their conceptual knowledge, 66% of the students raised their knowledge to compatible sketchy level and 17% of them were able to reach compatible elaborate level. In other words, conceptual change process occurred and almost all of the students somehow repaired their misconceptions. Considering that 83% of the students had high-level epistemological beliefs and 83% of the students had conceptual change, it can be assumed that when students had sophisticated epistemological beliefs, they could learn scientific concepts.

Students 10, 11 and 15 did not gain any scientific conception. Student 10 had medium-level epistemological beliefs. Nevertheless, he did not show interest to lessons and preferred to talk with Student 11 rather than participated into the class. Student 11 and Student 15 held high-level beliefs. These students had self-confident and taught that they did not have to attend the class to learn. From their points of view, they could learn by studying themselves.

Table 4 shows the correlation values between epistemological beliefs and conceptual change. Table 3 indicates a relationship between epistemological beliefs and conceptual learning. Nevertheless, according to Table 4, there was not any correlation between any of the dimensions of epistemological beliefs and conceptual change. This result is not in line with the results presented by Braten and Stromso (2004). They found that students who believed that learning occurs quickly or not at all were less likely to adopt mastery goals and more likely to adopt performance-approach and performance-avoidance goals. Moreover, the result of the current study is inconsistent with previous findings, which revealed that students’ beliefs assessed with Schommer’s general measure were significantly related to comprehension (Schommer, 1990) and conceptual change (Qian and Alvermann, 1995). The reason for this inconsistency might be the domain specificity. The students’ conceptual change was only measured in the domain of physics whereas their epistemological beliefs were assessed in terms of general knowledge. Another study
compared epistemological beliefs in the domain of physics with conceptual change in physics and found a relationship between them (Authors, in press).

**Conclusions and Implications of the Study**

The current study attempted to determine high school students’ epistemological beliefs and to find a correlational relationship between their beliefs and their conceptual change. The following conclusions can be drawn from the study. First, high school students’ general epistemological beliefs are very close to sophistication. Second, students have more sophisticated beliefs about the acquisition of knowledge while they have less sophisticated beliefs about the nature of knowledge. Third, there is no relationship between students’ general epistemological beliefs and their conceptual change in physics.

This research was conducted with the small number of participants. However, it would contribute to the literature toward a better understanding of high school students’ epistemological beliefs. This research has implication of presenting non-existence relationship between beliefs and conceptual learning.

**References**

Authors (in press). European Journal of Physics Education.


Development and Administration of Concept Survey on Wave Particle Duality and Uncertainty Principle for Undergraduate Students: A Pilot Study

Sapna Sharma, Department of Physics, St. Bede’s College, Shimla 171 002, India
P.K. Ahluwalia, Department of Physics, Himachal Pradesh University, Shimla 171 005, India.

Abstract

Effective teaching encompasses knowledge of what prior beliefs learners bring to the classrooms and evaluating how these beliefs change during or after instruction. Researchers have designed and developed a number of conceptual surveys/inventories covering different physics domains such as Force Concept Inventory to gauge student prior knowledge and assess learning. Solid state physics is the largest branch of condensed matter physics which deals with the study of the structure properties of solids and the relationship between the phenomenon of solids and physical principles behind them. Quantum mechanics is the key to understand the fundamental properties of matter, which is a collection of large number of microscopic particles \(10^{23}\), their spectra and chemical behavior. It fundamentally describes the behavior of particles at the atomic level and states that matter and energy have the properties of both particles and waves. Therefore, we find that a good conceptual understanding of themes of wave particle duality and uncertainty principle is very essential for the learners, before they go ahead with the learning of a solid state physics course. In fact wave nature of photons and electrons laid the foundation of solid state physics through classical Laue diffraction and Davison and Germer diffraction by crystals. This paper describes a preliminary study of developing an assessment tool to gauge the student’s prior knowledge and depth of understanding of these two themes, which is a prerequisite for understanding the course on solid state physics at undergraduate level i.e. Bachelor of Science (B.Sc.) three years course. In this paper we discuss the main steps involved in the development of the seventeen- items (version 1.0) of the survey including validation and reliability and preliminary results of gains (pretest to posttest) administered on students in four colleges and a sample of teachers attending a refresher course in physics as well. The percent score of the students on most of the items lies below the 60 % conceptual threshold inferring that they will have poor problem solving capabilities.

Keywords: quantum mechanics concept survey, reliability, validity

Introduction

Solid state physics is the foremost branch of condensed matter physics which studies the behavior of atoms placed in close proximity to one another. However, students while studying it finds an invasion of usage of various concepts drawn from fundamental concepts of physics like statistical mechanics, electrodynamics and quantum mechanics. Construction of solid state physics as a special domain of physics builds itself heavily on the foundation of the concepts of quantum mechanics. It also demonstrates how quantum mechanics, a physical theory make us understand the real world despite the fact that its foundation is probabilistic in nature requiring epistemological approach to Quantum Mechanics [1]. Also it is quite exciting to students that the modern solid state electronic devices like transistors, semiconductors and phenomenon like superconductivity can be appreciated and their working can be explained only by using the principles of quantum mechanics. Quantum mechanics is without doubt a key to understand the fundamental structure of matter, which is a collection of large number of microscopic particles \(10^{23}\) and variety of the forms of the matter through the spectra and chemical behavior of their constituents. It describes the behavior of particles at the atomic level and states that matter and energy have the properties of both particles and waves. In fact wave nature of photons and electrons laid the foundation of solid state physics through classical Laue diffraction and Davison and Germer diffraction experiments on crystals [2]. Therefore, it is expected that a good conceptual understanding of quantum mechanics is a must for the students, before they start learning the solid state physics course. In nut shell, we can say that concepts of quantum mechanics are the building blocks of solid state physics.
Also researchers have proved that students enter their classrooms with some prior knowledge, understanding and beliefs [3] sometimes described as alternative conceptions. Numbers of cognitive studies have underlined the fact that for an effective teaching and learning the new knowledge should be integrated with these prior beliefs. To gauge the correct conceptual understanding of learners, assessment tools are needed from across the content which has emerged as an effective research tool in the domain of Physics Education Research. In this paper, in the context of solid state physics course to be taught at undergraduate level, where direct implication or relevance of quantum mechanics is involved, some fundamental quantum mechanics concepts have been identified for which students should have a working knowledge before they are able to go ahead with solid state physics course. Based upon such two basic concepts: wave particle duality and uncertainty principle a conceptual survey has been designed in which, several questions focusing on a single concept are included to assess an accurate prior knowledge of students and to check post instructional improvement/gain if any.

**Objective**

The three fold objectives of our work are:

- to develop and design an assessment/diagnostic tool such as concept survey/inventory, to test the conceptual understanding of quantum mechanics and check whether the students have working knowledge of quantum mechanics to go ahead with the study of the solid state physics at the undergraduate level (Bachelor of Science B.Sc.).
- to identify through the well designed, validated and reliable items, common conceptual difficulties and learning gaps held by students in quantum mechanics needed for the understanding of solid state physics course.
- to execute certain strategies to bridge those gaps leading to significant change in the alternative conceptions in the minds of students towards expert views.
- In this paper we focus on the first two objectives only and third objective is in the process of being probed and implemented.

**Literature Review**

There are number of conceptual surveys/inventories designed and developed by researchers covering different physics domains [4-8]. When administered at the start of the new course, these surveys provide the picture of starting knowledge of the students and when administered at the end of a course, it gives feedback on those concepts that may need more attention or reveal the alternative conception held by the learners. By studying the wrong answers chosen by students for various questions, one can find out common misconceptions that persist even after instruction. These surveys have acted as a valuable tool for the teachers to find the misconceptions/alternative conceptions held by their students about that particular topic(s) and to develop new strategies to help them change towards expert view. Well known concept Inventories/surveys include Force Concept Inventory [4], the Force and Motion Concept Evaluation [5], the Electricity and Magnetism Concept Survey [6], the Quantum Mechanics Visualization Instrument [7] and Material Concept Inventory [8].

Since we were looking at various concepts of quantum mechanics relevant to solid state physics, we did an exhaustive literature survey on the themes of quantum mechanics and came across conceptual inventories like Quantum Mechanics Conceptual Survey (QMCS) [9] targeted towards the assessment of conceptual understanding of quantum mechanics of students to measure relative effectiveness of different curricula and teaching techniques, Quantum Physics Conceptual Survey (QPCS) [10], to assess students understanding of quantum mechanics at introductory level and tutorials on quantum mechanics [11], which focuses on conceptual and mathematical barriers faced by students in understanding and learning of quantum mechanics. These Inventories/surveys have helped us to frame our questions for the present survey in the context stated in the introduction.
Methodology

The process of development of concept inventory on quantum mechanics has gone through the following steps [12-13].

1) Defining of themes:

In order to know that which quantum mechanics topics are used in solid state physics course, we analyzed the syllabus of solid state physics course which is taught to final year students of three years undergraduate degree course prescribed in B.Sc. (Honours and General) in Physics of Himachal Pradesh University, Shimla, India, where the authors are involved in undergraduate and postgraduate teaching of physics. The quantum mechanics themes and scope limited for the relevant domain used in different topics of solid state physics were identified.

2) Content Validity:

Content validity was done with the help of teachers teaching undergraduate physics at colleges, affiliated to Himachal Pradesh University Shimla, India, and also teachers from post graduate departments of physics in the university. They constituted the experts group with whom discussions were held for identifying and limiting the scope of the survey.

3) Drafting of questions:

The concept survey presented here contains question items based upon content defined. The question items were drafted in the multiple choice format using text books [14-18] and research done by experts [19-31] involved in Physics Education Research and some websites.

4) Students Interview:

To sense students understanding of solid state physics course and what makes them feel this course is difficult, we conducted an interview with a group of fifteen students of B.Sc. III, who had recently studied solid state physics course and who were quite candid in sharing their confusions. When we probed them, we found that they were not able to link and appreciate particularly the concepts of quantum mechanics which they had already studied, when applied to solid state physics, where the application of quantum mechanics leads to unraveling a variety of interesting phenomenon related to real materials. Students have an impression that solid state physics course is very confusing particularly because it uses too many concepts which are rarely touched upon in the class of solid state physics. The interview lasted for almost one hour. It was taped transcribed and analyzed. This interview helped us to appreciate the missing linkages and a perception of learning gaps. It provided an opportunity to identify several common concepts of quantum mechanics which needed to be emphasized and learnt well for understanding solid state physics course.

5) Reliability and Validity:

The survey was evaluated on the basis of two major tests namely reliability and validity. Reliability is the consistency of test scores over repeated administrations. Reliability of the survey was measured using cronbach’s alpha coefficient. For validity, item analysis which includes item difficulty test and item discrimination test was performed.

Sample and mode used

The first version of the survey presented here consisted of 17 questions (see Appendix) based on multiple choice format as per the concept profile given in Table1. For pilot testing, it was administered in the form of pre test and post test to 90 undergraduate students studying in four different colleges of Shimla, affiliated to Himachal Pradesh University Shimla, India. The test was also administered to 21 teachers teaching physics in the different colleges all over the country (India) and under going a refresher course of three weeks duration in physics at Academic Staff College (ASC), Panjab University Chandigarh India. Test was administered to the students at the beginning and end of the course. Ten days advanced intimation for the administering of the test was given to all the target group members. Both teachers and students took almost forty five minutes to an hour to complete the test.
Table 1. Concept profile of quantum mechanics used in solid state physics

<table>
<thead>
<tr>
<th>Concept Profile</th>
<th>Questions</th>
<th>Topics of solid state physics course in which concept(s) is/are used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theme1: Wave- particle duality</td>
<td>1-14</td>
<td>Diffraction methods, lattice vibrations, nano science, superconductivity</td>
</tr>
<tr>
<td>Theme2: Uncertainty principle</td>
<td>15-17</td>
<td>Nano science</td>
</tr>
</tbody>
</table>

**Results and Discussion**

In the following section we present the preliminary results of the validity, reliability tests of the survey and pre-post tests on students. The gain observed in the performance by students is also discussed.

**A. Validity (Item Analysis)**

I. Item Difficulty Index:

Difficulty of various question items is calculated in terms of item difficulty index. Item difficulty index is the fraction of students who answered the given question correctly [32]. The higher value of difficulty index indicates that question is easy. Figure 1 (a) and (b) shows average difficulty index of questions on the two themes focused in this paper. It ranges from 0.2 to 0.6.

II. Item Discrimination Index:

The item discrimination index tells how well students whose overall scores put them in top upper half of sample performed on any specific question in comparison with students in the bottom half. It can have value from -1 to +1. The closer the value is to one, the more the test distinguishes between students. The average discrimination index as shown in figure1 ranges from a low 0.03 to a high of 0.44. In general the discrimination index should be 0.3 [32] or above, for an item for which no revision is required. Six question items (item nos.3,4,5,10,13,14) in this tool were having values above 0.3. Item with in the range 0.2 to 0.29 needs little revision. Seven items (Item nos.7,8,9,11,12,16,17) fell in this range. Four items (item nos.1,2,6,15) were having very low discrimination index and need complete revision.

![Figure 1. Average difficulty and discrimination indices](image)

**B. Reliability (Test Analysis):**

As stated earlier reliability refers to the consistency of test scores over repeated administrations. Reliability can be measured using Cronbach’s alpha reliability coefficient, which ranges from 0 to 1. A higher value of coefficient indicates good test reliability. But according to Adams and Wiemann, instruments designed to measure multiple concepts may have low value of Cronbach’s alpha [9]. In the present case Cronbach’s alpha came out to be 0.39, which is low. We were expecting that the value will come out to be low because as it was clear in the discussion with students that they were either weak or lacking in connecting the concepts.
**C. Pre-Post changes in performance of students**

Figure 2a shows the distribution of correct answers for pre-test and post-test.

![Figure 2a](image)

**Figure 2a.** Percentage of students answering correct for pre-test and post-test.

FCI [4] has called score of 60% on concept inventory/survey as conceptual threshold and mentioned that below this threshold a student’s grasp on concepts is insufficient for problem solving. If we look at figure 2b, we find that in all the questions of survey, Majority of percentage of scores for different items is below this threshold value indicating poor problem solving ability of the surveyed students.

![Figure 2b](image)

**Figure 2b.** Percentage of score of each student answering correct for pretest and posttest.

**Gain in Performance:**

The average normalized gain \( \langle g \rangle \) is defined as ratio of actual average gain to maximum possible average gain [33]

Average normalized gain \( \langle g \rangle = (\% \text{ posttest} - \% \text{ pretest})/ (100 - \% \text{ pretest}) \).

It is divided into three categories:

1. high average normalized gain \( \langle g \rangle > 0.7 \)
2. medium average normalized gain \( 0.3 < \langle g \rangle < 0.7 \)
3. low average normalized gain \( \langle g \rangle < 0.3 \)

And the absolute gain \( \Delta \) is defined as

\( \Delta = (\% \text{ of post test correct answers} - \% \text{ of pre test correct answers}) \).
Table 2 summarizes the normalized gain and absolute gain in students’ performance on the two themes.

<table>
<thead>
<tr>
<th>Theme</th>
<th>% Pre test score</th>
<th>% Post test score</th>
<th>Average Normalized gain &lt;( g )</th>
<th>Absolute gain ( \Delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave particle duality</td>
<td>36.66</td>
<td>39.91</td>
<td>0.05</td>
<td>3.3</td>
</tr>
<tr>
<td>Uncertainty principle</td>
<td>34.56</td>
<td>37.27</td>
<td>0.04</td>
<td>2.7</td>
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</table>

It is observed that average normalized gain is 2.9 in theme wave particle duality and 2.4 in the theme uncertainty principle, i.e. in both the concepts being tested, there is a low normalized gain level and learners were having conceptual difficulties even after the instructions.

**D Teachers Vs. Students Comparison**

We also compared the performance of students with teachers considered to be a know all expert group by a majority of students. Table 3 summarizes the results of statistical analysis arrived at.

<table>
<thead>
<tr>
<th>General statistics</th>
<th>Mean</th>
<th>Mode</th>
<th>Median</th>
<th>Std. Dev</th>
<th>Skewness Coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students (pre)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>2.41</td>
<td>0</td>
</tr>
<tr>
<td>Students (post)</td>
<td>6.3</td>
<td>5</td>
<td>6</td>
<td>2.1</td>
<td>0.428</td>
</tr>
<tr>
<td>Teachers</td>
<td>8.86</td>
<td>8</td>
<td>9</td>
<td>2.29</td>
<td>-0.183</td>
</tr>
</tbody>
</table>

We observe that

- Mean Mode and Median coincide in pre test of students and the scores follow normal distribution Fig 3a. The curve in post test appears to be slightly off from a normal distribution towards a perceptive shift in mean score from 6 to 6.3. We also calculated the skew of the scores. The value of skew coefficient came out to be slightly positive. This indicates that there are more scores at the low score end and students found test to be more difficult in post test.
- There is a shift towards higher mean scores from pre-test to post-test.
- The standard deviation in scores of students is reduced from pre-test to post-test.
- Mean Mode and Median are almost same as given in Table 3 in case of teachers’ scores and curve nearly followed normal distribution (Fig 3b)
- We also calculated the skew coefficient. It was negative in the case of teachers. This indicates teachers found test to be slightly on the easier side.

![Figure 3a. Frequency of pre-post score (Students)](image-url)
Figure 3b. Frequency Distribution Curve (Teachers)

Figure 3(a, b): Percentage of students answering correct for pretest and posttest and percentage of teachers answering correct

Conclusion

It is very well established that Physics Education Research based Concept surveys/inventories play an important role to improve student learning. Sometimes, we as a teacher overestimate our students’ prior knowledge without checking, and try to build new knowledge on a shaky foundation. Present study highlights the need of prerequisite concepts of quantum mechanics before the starting of an undergraduate solid state physics course. One of the best ways to check this is to use the concept survey/inventory. In this paper a survey has been developed and presented. The survey comprised 17 questions based on two concepts wave particle duality and uncertainty principle was administered before and after a course to undergraduate students of four different colleges of the city. Statistical analysis based on the sample of 90 students and 21 teachers indicated that survey is reliable with satisfactory Cronbach’s alpha coefficient, and valid measure of conceptual knowledge. This test helped us to see students’ performance and struggle in two concepts, as there was a low average normalized gain in performance even after the instructions of full year. According to FCI, less than 60% score of students indicate their poor problem solving ability. We found that students were scoring less than 60% in majority of question items indicating their problem solving incompetence of quantum mechanics. Also when we compared teachers’ students’ performance, we found that teachers were finding this test slightly on easier side as compared to students though there mean score was not very high. In future the information and analysis on student thinking on these questions will also be made and reported by conducting interview sessions.

References

   http://prstper.aps.org/abstract/PRSTPER/v6/i2/e020121
Appendix

1) A proton has a slightly smaller mass than a neutron. Compared to a neutron, a proton of the same wavelength \( \lambda \) would have
   (a) more kinetic energy
   (b) less kinetic energy
   (c) same kinetic energy.

2) An image of a bat fly can be made using a beam of electrons rather than a light beam. The properties of electrons which make them useful for imaging such fine details are
   (a) electrons can be given a large momentum and hence larger wavelength
   (b) electrons can be given a large momentum and hence shorter wavelength
   (c) electrons can be given a small momentum and hence smaller wavelength

3) Calculate the de Broglie wavelength of a person walking through a doorway. Take mass of the person 75 kg and velocity 1 m/s. Will the person exhibit wave-like behavior when walking through the single slit of the doorway?
   a) 0.80\( \times 10^{-34} \) m, Yes, person will exhibit wave behavior
   b) 0.08\( \times 10^{-34} \) m, No, person will not exhibit wave behavior
   c) 0.80\( \times 10^{-34} \) m, No, person will not exhibit wave behavior
   d) 0.08\( \times 10^{-34} \) m, Yes, person will exhibit wave behavior

4) A photon and an electron each have the same energy of 20.0 eV and their wavelengths are 620 nm and 0.274 nm respectively. You want to study an organic molecule which is about 250 nm long using either a photon or an electron microscope. Approximately what wavelength should you use and which probe is likely to damage the molecule the least?
   a) wavelength 620 nm and photon probe
   b) wavelength 250 nm and photon probe
   c) wavelength 250 nm and electron probe
   d) wavelength 0.274 nm and electron probe

5) What is the de Broglie wavelength of red blood cell, with mass 1\( \times 10^{-11} \) g that is moving with a speed of 0.400 cm/s. Do we need to be concerned with the wave nature of the blood when we describe the flow of blood in the body?
   (a) 1.66\( \times 10^{-17} \) m, No
   (b) 1.66\( \times 10^{-17} \) m, Yes
   (c) 1.66\( \times 10^{-17} \) m, No
   (d) 1.66\( \times 10^{-17} \) m, Yes
6) If your wavelength were 1.0 m you would undergo considerable diffraction in moving through a doorway. What must be your speed to have this wavelength? (Assume your mass is 60 kg). Will you notice diffraction effect as you walk through doorways?

(a) $1.1 \times 10^{-35}$ m/s, No
(b) $0.11 \times 10^{-35}$ m/s, No
(c) $0.11 \times 10^{-35}$ m/s, Yes
(d) $1.1 \times 10^{-35}$ m/s, Yes

7) Which one of the following statements correctly describes the wave–particle duality concept?

(a) If waves have particle properties, then particles have wave properties.
(b) Particles can have wave properties, but waves cannot possibly have particle properties.
(c) Although a wave can have particle properties, it is absurd to consider a particle to behave like a wave.
(d) The whole thing is ridiculous. Waves have wave properties, and particles have particle properties.

8) Which one of these statements is true about an atom excited by interaction with a photon?

(a) Electrons can be raised to any level you like and then fall back to their ground (stable) state.
(b) Electrons can only be raised to discrete energy levels, then fall back to their ground state.
(c) Electrons can be raised to any level you like and then stay in that state.
(d) Electrons can only be raised to discrete energy levels, then stay in that state.

9) Which one of the following best describes the way that an individual photon travels?

(a) In a straight line and in one direction only
(b) In a straight line but can travel in two directions at the same time.
(c) In a circular path of large radius.
(d) In a circular path of small radius.

10) If an atom is struck by a photon, its energy changes. By how much?

(a) Its energy does not change at all.
(b) Less than the energy of the photon
(c) The energy of the photon
(d) More than the energy of the photon.

11) You see an electron and a neutron moving by you at the same speed. How do their wavelength $\lambda$ compare?

(a) $\lambda_{\text{neutron}} \geq \lambda_{\text{electron}}$
(b) $\lambda_{\text{neutron}} < \lambda_{\text{electron}}$
(c) $\lambda_{\text{neutron}} = \lambda_{\text{electron}}$

12) Do you think neutrons, with no electric charge, still would have a similar diffraction pattern as electrons?

(a) No, diffraction depends upon charge
(b) Yes, diffraction is independent of charge
(c) Can not say

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13) A visible light beam is used in the analysis of a crystal structure. Estimate the minimum lattice constant for such a crystal amenable to analysis by visible light for the first order diffraction.
   (a) 200nm-350nm
   (b) 2000nm-3500nm
   (c) 400nm-700nm
   (d) 4000nm-7000nm

14) Mass of neutron is 1836 times the mass of an electron. Energy of neutron beams employed in crystal diffraction will be
   (a) larger than energy of electron beam
   (b) smaller than energy of electron beam
   (c) same as energy of electron beam

15) A 1.5 mg troublesome mosquito is annoying you as you attempt to study physics in your room, which is 5.0m wide and 2.5 m high. You want to swat the insect as it flies towards you, but you need to estimate its speed to make a successful hit. What is the maximum uncertainty in the horizontal position of the mosquito and what limit does the Heisenberg uncertainty principle place on your ability to know the horizontal velocity of the mosquito?
   (a) 5m, 1.4x10^{-29} m/s
   (b) 1.25m, 1.4x10^{-29} m/s
   (c) 5m, 14x10^{-29} m/s
   (d) 1.25m, 14x10^{-29} m/s

16) The neutral pion (π^0) is an unstable particle produced in high energy particle collisions. Its mass is about 264 times that of electron, and it exists for an average lifetime of 8.4x10^{-17} s before decaying into two gamma ray photons. What is the uncertainty in the mass of the particle?
   (a) 1.39x10^{-34} kg
   (b) 1.39x10^{-35} kg
   (c) 13.9x10^{-35} kg

17) The Uncertainty Principle implies that
   (a) If we measure, for example, the position of a particle with certainty, the result of the measurement for that system if repeated has some distribution and results are close to each other but not exactly the same
   (b) If we measure, for example, the position of a particle with certainty. We have changed its momentum so the result of measurement of momentum is uncertain.
   (c) We can not measure either momentum or position of a microscopic particle, because it acts like a wave and wave is not localized.
   (d) In a microscopic system, we do not have good tools to measure momentum and position at a single instant of time.
   (e) The electron has a position but no trajectory and an unknown momentum
   (f) The electron in an atom has a definite but unknown position.
Rotations from a New Perspective: Experiments, Modelling and Analogies Based on Angular Momentum as an Extensive Quantity

Alessandro Ascari, Fondazione Ducati, Bologna, Italy
Federico Corni, Università degli studi di Modena e Reggio Emilia, Modena, Italy
Tommaso Corridoni, SUPSI-DFA, Locarno, Switzerland
Michele D’Anna, Liceo Cantonale di Locarno, Locarno, Switzerland
Giovanni Savino, Fondazione Ducati, Bologna, Italy, Università degli Studi di Firenze, Firenze, Italy

Abstract

Concepts and mathematical instruments used in elementary mechanics are often perceived as abstract entities by students. We propose therefore an approach to the description of rotational mechanical processes based on a conceptualization of angular momentum grounded on image schemes and analogies from common everyday experience (Fuchs, 2007). In our approach angular momentum is described as a conserved extensive quantity, whose balance equation is either an instrument to foster clear mental images of rotational processes, or a solid base for algebraic development. Exploiting analogies, in this work we show how this way angular momentum can be stored in rotating bodies, how their moment of inertia represents their angular momentum capacities, and finally how a torque applied to a rotating body can be imagined as an angular momentum flow. We analyse from this point of view three experiments, using on-line data acquisition and dynamical modelling. The use of analogies allows indeed to develop dynamical models in a wide range of contexts, able to strengthen basic concepts and discuss phenomena in relation with the initial conditions and the parameter values.

Introduction

Educational research points out widespread learning problems in mechanics. We propose an approach based on a conceptual revision at the disciplinary level explaining how our usual perception of reality is grounded on image schemes, common among different aspects of human experience (Fuchs, 2007).

The usual description of mechanical processes starts from kinematics, although concepts and mathematical instruments are perceived this way as abstract entities by students.

Our approach is based on extensive mechanics quantities like momentum and angular momentum, whose balance equations, besides being a solid base for algebraic development, permit to develop clear mental images of processes. Coherently with this approach, we use analogy between models as a powerful way to understand mechanical systems and processes.

This contribution highlights the advantages of such an approach combined with technological tools as on-line data acquisition devices and dynamical modelling software.

In the next paragraph we show the conceptual framework, giving in the subsequent paragraphs an overview of three didactic experiences coming from the informal context of a science centre and the formal one of a school laboratory.

Angular momentum as stored quantity

Classical mechanics defines the angular momentum $L$ stored in a rotating body starting from its moment of inertia $I$, referring to the rotation axis, and the angular velocity $\omega$, according to:

$$L = I \omega$$  \hspace{1cm} (1)
Further, the rate of change of angular momentum is related to the (total) torque $\tau$ acting on the body:

$$\frac{dL(t)}{dt} = \tau(t)$$

(2)

This balance law suggests that torque $\tau$ can be interpreted as the intensity of angular momentum flow, allowing the construction of a physical model by means of analogical reasoning, starting from simple experiences in hydraulic context.

Everyday life shows indeed that water can be stored in recipients, and its amount can be changed by a flow, i.e. an exchange with its surrounding. As a matter of fact, water can flow through holes or pipes connecting recipients with different levels of water.

In particular, the physical quantity *volume of water* $V$, stored in a recipient, can be expressed through the capacitive law:

$$V = C \rho$$

where $C$ is the hydraulic capacity of the recipient and $\rho$ the hydrostatic pressure at the bottom of the recipient itself, given by:

$$\rho = \rho g h$$

where $h$ is the level of water, $\rho$ its density and $g$ the intensity of the gravitational field. In particular, for a recipient of constant section $A$ we have:

$$V = A h \quad C = \frac{A}{\rho g}$$

As the quantity *volume of water* $V$, also angular momentum can be thought by analogy as an extensive substance-like quantity which can be stored in a rotating body of moment of inertia $I$ and angular velocity $\omega$, so that also equation (1) represents a capacitive law, as equation (2) represents the corresponding balance equation. This means that a body changes its rotational state when an angular momentum flow, i.e. a torque, brings/takes away $L$ to/from it. In the case of interacting bodies, therefore, the angular velocity difference is the quantity determining the direction of angular momentum’s flow. In particular, considering only rotational phenomena, two bodies can exchange $L$ only if they are rotating at different angular velocities (as water, in pure hydraulic processes, flows only when a pressure difference is given) (Fuchs, 2002; Fuchs, 2007).

This mental representation, obtained by analogy between models of extensive quantities behaviour, is the base of our approach to explain rotational mechanics.

We now show three didactical experiments to let the reader understand how the interpretation of rotational processes can be based on the point of view sketched above.

A. In the first example we present a rotational collision process, i.e. a short interaction between two rotating wheels. Angular momentum conservation will be discussed too.

B. The second example focuses instead on what happens during the interaction between two wheels exchanging angular momentum for a longer time.

C. In the last example, the angular momentum change in a body spinning and varying its moment of inertia is finally studied.

For each example we show at first a hydraulic model and then a quantitative analysis based on a dynamical model. According to the previous analogy between water volume and angular momentum, hydraulic models provide a powerful representation of mechanical processes, while dynamical models, designed with a software which allows to work on a graphical surface (Fuchs, 2002), translate the hydraulic model in a four-symbol language:
• the stock, representing the amount of a quantity which can be brought in or out via a flow;
• the flow, which can carry the same quantity from a stock to another one;
• the circle, which represents a parameter, as capacity, or a constant, as \( p \) or \( g \);
• the arrow, which points out a relationship between stocks, flows and/or parameters.

The proposed models has been made using the software STELLA (www.iseesystems.com). Obviously, for this purpose several other computing instruments can be used: from an electronic spreadsheet to one of the wide variety of software products on the market.

2.A. Inelastic collision between two disks

Two coaxial Plexiglas disks are mounted on a low-friction axis (Fig.1). When the upper one is raised, the two disks rotate independently; when it is lowered they hit, bringing into contact each other via pieces of rubber (stuck on the upper surface of the lower disk).

![Experimental setup for inelastic collision between disks. Each disk is provided with a rotary motion sensor to measure angular velocity vs. time.](image)

At the beginning of the experiment, the upper disk is raised, and both disks are put in rotation at different angular velocities. When the upper disk is abruptly lowered, it is slowed/accelerated from the lower one, which is instead accelerated/slowed, until the whole system of the two disks moves at the same angular velocity.

In the graph below (Fig. 2), the measured angular velocities of the disks are represented vs. time. The interaction time (~0.10 s) is short enough to allow us to neglect, during the inelastic collision, small friction effects.
Figure 2. Experiment A: angular velocities measured vs. time. When the two disks are not in contact, their angular velocities change very slowly under the action of friction with the rotation axis. The interaction time (~0.10 s) is short enough to allow us to neglect this friction effect during the inelastic collision. The changes in the angular velocities during the collision are different because the two disks have different moments of inertia. The graph shows the angular velocity of the sensors: in order to obtain the angular velocity of the disks it is necessary to take into account the ratio between the radii of the pulley and the disk.

It is worthwhile to note at this point the analogy with inelastic collision between two carts moving with different speeds: as the first cart hits the second one, they move together, and their final common velocity, as well known, can be calculated using linear momentum conservation.

In the rotational collision, linear momentum is replaced by angular momentum and translational velocity by angular velocity, but the process can be described the same way.

When the two disks are separated, the angular momentum of the upper disk (L1) or that of the lower one (L2) change only by the action of the torque due to friction with the rotation axis, so that their angular velocities (ω1 and ω2 respectively) slowly decrease (Fig. 2). When the upper disk is lowered, as long as there is an angular velocity difference, an additional torque due to friction between the two disks appears. Therefore there is a flow of angular momentum which intensity and direction depend on the chosen initial conditions. In Fig. 2, for instance, angular momentum flows from disk 1 to disk 2, raising its angular velocity ω2, and therefore its angular momentum L2, being its moment of inertia constant. This process stops when both disks rotates at the same angular velocity, which, as well known, can be calculated using angular momentum conservation.

Following our approach, we now develop a hydraulic model of this first situation in order to reach a deeper and more general insight in dynamical systems time evolution, useful to obtain a model of rotational processes effective also in more complex situations, as those in examples B and C.

We replace the two disks with two water tanks connected by a pipe opened or closed with a tap (which modulates the interaction), each tank having a small hole in the bottom (representing the constant inner
friction of the support system). The two tanks have different base areas (i.e. different hydraulic capacities), so they contain different amount of water even if the water levels inside them are the same (Fig. 3).

Figure 3. Experimental setup for hydraulic analogy: two communicating vessels are equipped with additional pipes in order to exchange water with the environment. In each connection, a tap permits to modulate the intensity of the water flow.

The experiment is as follows: at the beginning the tap in the connecting pipe is closed and the two tanks are filled with different levels of water; only a small amount of water leaks through the holes in the bottom, lowering the levels of water. At a certain time, the tap in the connecting pipe is opened too, letting the water flow between the tanks. The water flow stops when the levels in the tanks are the same, i.e. when an equilibrium between pressures is reached.

The analogy is completed recognizing the following correspondences: water volume and angular momentum as extensive quantities subjected to balance equations; pressure differences and angular velocity differences as driving forces for hydraulic and rotational phenomena respectively; base areas of the tanks and moments of inertia of the disks as hydraulic and rotational mechanic capacities respectively.

In Fig. 4, this analogy is fostered by means of two dynamical models, one describing the two-disks system, the other the two tanks system. In both, stocks represent extensive quantities (angular momentum or water volume respectively) and blue thick arrows represent flows between stocks. The structure of the models is the same.
Figure 4. Dynamical models for the setup of experiment A (left) and its hydraulic analogue (right). For each disk/recipient, a tank for storage of angular momentum/water volume is introduced; thick lines represent the acting torques/water flows, i.e. the angular momentum/water volume flows. The parameter ‘b int’, related to the friction regulated by the clamp, has been imposed positive and constant only if there is an angular velocity difference.

The parameters of the dynamical models were determined independently with different experiments. We have interpreted the different interactions as constant flows over time.

Fig. 5 shows the angular velocities of the disks measured and calculated by the dynamical model, vs. time. The comparison is satisfactory, considering that the model reproduce the whole process, before, during and after the collision.

Figure 5. Experiment A: comparison of measured (2, 4) and calculated (1, 3) angular velocities. Even during collision, the model reproduces adequately the experimental data.
2.B. Magnetic interaction between two disks

In this second experiment the setup of the first is modified in order to control the interaction process between the two disks: they now interact by means of electromagnetic induction, whose length in time can be chosen a priori changing the distance between disks.

The apparatus used has (Fig. 6):

- an upper disk made of aluminium;
- a lower one made of plastic;
- the upper surface of the lower disk equipped with some magnets;
- the lower disk equipped with an adjustable (mechanical) friction, realized with a clamp.

Figure 6. Experimental setup for experiment B. Each disk is provided with a rotary motion sensor to measure angular velocity vs. time. The strength of the magnetic interaction can be changed varying the distance between disks.

At the beginning of the experiment, the lower disk is put in rotation, while the upper one is kept still by means of a stand, behaving as an electromagnetic brake. Then, the upper disk is released and it starts moving dragged by means of the electromagnetic inducted torque.

As in the previous experiment, both disks can possess angular momentum, but in this case only one is initially rotating. Furthermore, they experience different friction torques on their bearing systems. When the lower disk is rotating, its angular momentum decreases because of the torque produced by electromagnetic interaction between the magnets and the upper disk. Through this interaction, angular momentum is transferred from the lower to the upper disk, initially at rest, increasing its angular momentum, i.e. its angular velocity. The rate at which the angular momentum is transferred is given by the torque value, which is itself depending on the difference between the two angular velocities.
Regulating opportunely the three taps in the equipment shown in Fig. 3, the hydraulic system can behave analogously to the mechanical one for all different initial conditions. For instance, closing the tap in the connecting pipe partially, the intensity of the water flow can be reduced, extending therefore the interaction over a longer time.

Fig. 7 shows the dynamical model for the mechanical situation here considered: its structure is the same of that in Fig. 4, apart from the connection between torque interaction and torque friction for the upper disk, which permits to take into account the “grounding” of the upper disk while it is kept still by means of the stand (which obviously remains fixed to the Earth). The parameters describing the interactions were determined separately, with different experiments.

Figure 7. Dynamical model for the setup of experiment B. For each disk, a tank for storage of angular momentum is introduced; thick lines represent the acting torques, i.e. the angular momentum flows. The parameter defining the friction interaction can be measured in independent experiments for each disk.

Fig. 8 shows the angular velocities of the disks measured and calculated by the dynamical model, vs. time. The comparison is satisfactory. It is worth noting that with the chosen initial conditions, the sign of the difference between the angular velocities reverses (this means that the upper disk rotates longer than the lower one!).

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2.C. Variable moment of inertia of a body

In experiences A and B the angular momentum has been transferred between systems (among disks or environment) by means of interactions (collision, friction, electromagnetic induction). The transfer process has been in both cases visualized by a hydraulic model and quantified by a dynamical model, in order to reproduce real measures vs. time assuming hypothesis a priori, as balance equations and angular momentum conservation.

In the experience C, another step toward the goal of our approach, i.e. to let students relate phenomena to a more general model of rotational dynamics, is done. While in experiences A and B the influence of interactions on the angular momentum levels, i.e. the angular velocities, has been studied taking constant the angular momentum capacities of the interacting systems, i.e. their moments of inertia, in experiment C, the dynamical behaviour of the system is driven essentially changing its moment of inertia.

The system chosen for the experiment is a beam rotating around a vertical axis passing through the midpoint of the beam itself. During rotation, its moment of inertia can increase or decrease by making two objects of equal masses move towards the rotation axis or the extremities of the beam (fig. 9). The two objects are moved using a lead screw actuated by an electric motor mounted on the beam itself. The first objects is a person sitting in security conditions on a motorcycle mock-up and the second one is a simple counterbalance mass. The apparatus belongs indeed to “Fisica in Moto” (Physics on Motorbikes) of Fondazione Ducati, an educational laboratory for high school students, developed by engineers and technicians of the motorcycle manufacturer Ducati Motor Holding S.p.A. (see www.fisicainmoto.it for further details).

**Figure 8.** Experiment B: comparison of measured (1, 2) and calculated (3, 4) angular velocities. In the first part of the process, the upper disk is kept still.
Figure 9. Experimental setup for experiment C. The horizontal beam can rotate around the vertical symmetry axis. The two objects mounted on the beam have the same masses and have symmetric positions with respect to the rotation axis.

The red line in Fig. 10 represents the measured angular velocity. At the beginning of the experiment, the two objects are at the ends of the beam and the beam is still. During phase A in Fig. 10 a horizontal force (orthogonal to the beam) is applied at the extremity of the beam thus increasing the angular velocity of the system. In this phase the force intensity $F$ is measured vs. time. At the beginning of phase B the force is removed and the system starts to slow down due to the friction with the rotating axis. At the beginning of phase C the two objects start moving along the beam, both in the direction of the rotation axis, thus decreasing the total moment of inertia of the system. By angular momentum conservation, when the moment of inertia decreases the angular velocity increases as stated by equation (1). The objects reach their final position at the centre of the beam at the end of phase C. During phase D the overall system angular velocity slows down because of the sole effect of friction with the rotation axis and finally comes to a stop.

Figure 10. Experiment C: comparison of calculated (1) and measured (2) angular velocities. The model parameters are determined in the first two phases of the process (see text for further details).

The blue line in Fig. 10, refers to the results of the dynamical model represented in Fig. 11, accounting for all the phases of the considered process. Measures and dynamical model results match considering the torque needed to put in rotation the beam (‘$F$ measured’ in Fig.11) and a friction. In particular, the friction (‘torque friction’ in Fig.11), consists of a constant part, related to the inner friction of the bearing system, and a variable one, related to the moving beam within the air, increasing as the square of the angular velocity.
Figure 11. Dynamical model for the setup of experiment C. Only one tank, L, is needed to store the angular momentum of the whole system. The measured velocity v of the objects along the beam, allows to determine their distance R from the rotational axis vs. time, and therefore the moment of inertia as well. Thick lines represent the acting torques, i.e. the angular momentum flows.

3. Conclusions and outlook

We showed an approach to mechanical rotations based on angular momentum considered as a substance-like quantity. As a matter of fact we explained, by means of a friendly cognitive tool as hydraulic analogy, what happens during several rotational processes due to different kind of interactions, reproducing then with the help of dynamical modelling, the measured quantities involved, angular velocity, vs. time.

We showed three different real experiments. The first one, similar to a classical “linear” inelastic collision experiment, where essentially only the initial and final states are observed. Then, we showed a second more complex experiment, with a longer interaction time, permitting us to focus on the dynamics during the process. Finally, with the third experiment we considered a situation in which the moment of inertia was changed.

Our approach has been applied in both formal and informal contexts: while the first two experiments belong to a didactical physics laboratory of Liceo Cantonale of Locarno, the last one belongs to the science centre ‘Fisica in Moto’, a didactical laboratory of Ducati in Bologna.

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References


Discourse and Argumentation in an Urban Science Classroom

Patricia S. Dunac* and Kadir Demir, PhD

*Corresponding author Patricia Dunac (pdunac1@gsu.edu) is a PhD student at Georgia State University and a science teacher in Metro-Atlanta, GA. Kadir Demir (kadir@gsu.edu) is an assistant professor of science education in the Department of MSIT (Middle-Secondary Education & Instructional Technology) at Georgia State University in Atlanta.

Abstract:
We engaged secondary science students in a teacher and student constructed Uno Card Game (UCG) to change their conceptual understanding of the various energy transformations. The article outlines how we incorporated Toulman’s Argumentation Pattern, using discourse, in the UCG. The activity helped students develop the essential understanding of energy transformation, among and between different sources. Students experienced significant conceptual gain in their ways of thinking, in contrast to traditional teaching and learning practices. The collaboration and interaction between teacher-student(s) and between student-student fostered an environment where they became co-constructors of knowledge.

Keywords: 5E, Toulman’s Argumentation Pattern, Discourse, Argumentation, and Energy Transformation

Introduction
By the time students leave elementary school they should have learned how to distinguish between some forms of energy transformations (e.g. mechanical, electrical, and sound); however students only know how to distinguish between those that have perceivable effects (e.g. a student can recognize that a car has mechanical energy because of its motion, but will not identify the chemical energy that is stored in that system) (Brook & Driver, 1986). These gaps in knowledge form an introduction to alternative conceptions that are scientifically based and will persist throughout a lifetime; for example at the secondary level students believe: (a) energy is confined to some particular origin, such as the electricity the power company sells (Diagnoser, 2011); (b) only one form of energy is present at a time (Brook & Driver, 1986; Brook & Wells, 1988); and (c) when teachers’ state “energy is not created or destroyed,” they mean that energy is stored in the system and can be released again in its original form (Solomon, 1985).

When teaching this topic traditionally teachers use lectures, handouts, worksheets, and cookie-cutter labs. For example, in a recipe-like activity students work on an activity, in which they observe the potential energy of a bouncing ball with no thought into why and how the ball is moving and what types of energy is present. These types of practices are not structured around the essential tenets of inquiry (National Research Council, 2000). Most importantly, these alternative conceptions are not replaced with scientifically sound conceptual understanding of the phenomena. Traditional teaching and learning practices contradict reform oriented methods of engaging students with content. Reform oriented science teaching and learning practices states that science is not merely the acquisition and accumulation of facts, as seen in a traditional science classroom; rather it is the interplay of content with the social that allows for deep comprehension and true conceptual changes. There are many ways to address students’ common alternative conceptions (e.g. discourse, argumentation, facets of learning, metacognition, etc.) (Hewson, 1981). If educators are truly seeking to change students’ mental models of specific phenomena, then they must have their students embark on several confrontations with that concept. Sutherland and Sinatra (2003) suggest having students interact with the concept in an open format, allowing for the exchange of students’ perceptions and knowledge. Students need to confront their conceptions and discuss opposing views, rather than being told what their views should be. Being explicitly told what the scientific “rules” are will only allow for a quiet classroom; however, it will not change their alternative conceptions nor cause changes in their conceptual models.

In this paper we discuss how we integrate discourse and argumentation (Erduran, Simon, & Osborne, 2004) as pedagogical tools to address and rectify common alternative conceptions of energy transformations, in
the context of a 5E learning cycle (Bybee, 1997), using teacher and student created Uno (playing) cards. The Energy Transformation Uno Cards Game (UCG) was part of a larger unit on energy. During a six-week unit covering the Next Generation Science Standards (NGSS) (Pratt, 2012, see NGSS - PS3a and PS3b), students spent about six instructional days creating cards and playing the game. In the following section we outline this activity.

**Words with Friends: Energy Transformation Uno Cards Game**

Before the Energy Unit began, the teacher introduced Toulman’s Argument Pattern (TAP); Claims, Grounds, Backings, and Rebuttals, to students (Erduran, et al., 2004). The teacher provided an explanation and examples of each of these terms (see Table 1). For example, students were told that a “ground” was specific proof and it was used to support a given claim. In this case a ground could be the set of cards which supports their claim and confirms that their energy transformation is correct.

**Table 1.**

<table>
<thead>
<tr>
<th>Structure of Argument</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claim</td>
<td>an assertion put forward publically for general acceptance</td>
<td>I believe that this is a correct energy transformation set.</td>
</tr>
<tr>
<td>Grounds</td>
<td>specific facts relied on to support a given claim</td>
<td>This set of cards support my claim and this energy transformation is correct!</td>
</tr>
<tr>
<td>Backings</td>
<td>generalizations making explicit the body of experience relied on to establish the trustworthiness of the ways of arguing applied in any particular case</td>
<td>I have other examples that are close to this one, and they can support my belief that this set is correct.</td>
</tr>
<tr>
<td>Rebuttals</td>
<td>the extraordinary or exceptional circumstances that might undermine the force of the supporting arguments</td>
<td>I think you are wrong because there is another type of energy transformation that I’ve seen.</td>
</tr>
</tbody>
</table>

Adapted from Toulmin’s Argument Pattern – Toulmin, 1958

**Engage**

The activity started with an engaging question to puzzle and motivate students. The teacher grabbed a scrunchie from her hair and began to stretch it. As the teacher was stretching it to its maximum limits, the teacher posed that question “In your small groups, I want you to discuss what types of energy is present at each point of the scrunchie as I am pulling it apart?” The teacher posed this question to tap into students’ prior knowledge of energy transformations (e.g. the potential vs. kinetic energy in that system) and as a hook to engage students in the energy transformation phenomena. Having students share their initial observations of the phenomena allowed the teacher an opportunity to see where her students were. At this point some students could not see the transformations present; however they were able to see the change in the material. For example, Tina said, “It’s all potential when you stretch it;” however, when asked about the transformation during the stretch, she could not explain it. This was indicative of common students’ conceptual understandings of the phenomena when the teacher started the activity.
Explore

Following the initial engagement, the teacher introduced the Uno Card Game (UCG) to the students. The objective of UCG was to help students explore several forms of energy transformations. Before the students were given a chance to play the game in their groups (of 3 to 4 students), the teacher went over the rules (see Figure 2 for game rules) and reminded them of the TAP principals in which to convey their discourse, by giving them two examples. In one instance, the teacher posed a question for the class, “I’m trying to get rid of as many cards as possible, but in order to do that, I have to make sound arguments. Does anyone remember how we make arguments in class?” Sandra replies, “You make a claim” and Jeff jumps in and states “You give an example.” From this, students learned that claims could be made in science class (by whomever), but they had to have support. In another example, the teacher asked “What happens when you plug that toaster in?” Jamie replied, “The energy is transferred from electrical to thermal to radiant.” The teacher responded, “So does the energy disappear?” Kim yells, “It’s stored!” and Jada immediately rebuts “No it’s not! It’s transferred!” When asked how they know this to be true, John explains “it means that energy can’t be lost. It’s always around. You can’t get rid of it.” Kim continues and says, “When I use it, it doesn’t go away it goes to another form,” and finally Jada states, “even if we can’t see it.” Following these two examples, the teachers felt confident that students could use TAP to play UCG.

In their group, students worked relentlessly falsifying their peers’ claims based on the weakness of their arguments. In one example, Jamie, James, Paul and Sandra worked together. After the UCG cards were dealt, Jamie’s hand had seven cards, which included three pictures (a flashlight, car, and bow and arrow), and four words (chemical, electrical, sound, and radiant) (see Figure 3). Using Jamie’s prior knowledge and insight gained from the group, he made a claim that a flashlight has “chemical energy stored in the batteries; electrical energy when the electrons are moving from the battery to the flashlight; and radiant energy when it emits light.” His peers agreed with his claim and backing, and allowed him to release four cards (the picture of the flashlight, and the cards that stated: chemical energy, radiant energy, and electrical). Jamie now had three cards remaining: (1) the car, (2) bow and arrow, and (3) the word sound.
With various random cards in his hands, James attempted to play his hand after Jamie. He realized that his card collectively, could not make a complete set. James cards consisted of the words (thermal, sound, nuclear, and mechanical) and pictures (guitar, remote control, and a telephone) (see Figure 4). After reflecting on his cards, he realized that he could not make a complete set; however, he could add to the fold that Jamie had just presented. He placed the UCG “thermal” card on top of Jamie’s set. His peers were baffled and refuted his claim. Sandra states “you can’t do that!” Jamie posited “why can’t I add my card?” Paul responds, “Because it’s not a complete transformation.” Sandra chimes back in “If it’s not a complete set we’ll just do a rebuttal and you’ll have to pick up four cards.” James states that it is a valid addition, because “although the batteries stored chemical energy, and it transfers to electrical, which eventually gives it light, there is a source of heat that is transferred when the flashlight is powered on.” The students reflect on James’ backings and they all agree.

Figure 2.

With various random cards in his hands, James attempted to play his hand after Jamie. He realized that his card collectively, could not make a complete set. James cards consisted of the words (thermal, sound, nuclear, and mechanical) and pictures (guitar, remote control, and a telephone) (see Figure 4). After reflecting on his cards, he realized that he could not make a complete set; however, he could add to the fold that Jamie had just presented. He placed the UCG “thermal” card on top of Jamie’s set. His peers were baffled and refuted his claim. Sandra states “you can’t do that!” Jamie posited “why can’t I add my card?” Paul responds, “Because it’s not a complete transformation.” Sandra chimes back in “If it’s not a complete set we’ll just do a rebuttal and you’ll have to pick up four cards.” James states that it is a valid addition, because “although the batteries stored chemical energy, and it transfers to electrical, which eventually gives it light, there is a source of heat that is transferred when the flashlight is powered on.” The students reflect on James’ backings and they all agree.

Figure 3
After James successfully defends his claim, Paul decides to try his luck with the group. In his hands he has four pictures (a house with solar panels, a lawn mower, a windmill, and a crane); additionally, he has three cards with words (a wildcard, a reverse card, and chemical card) (see Figure 5). With this hand, Paul decides to place his wildcard and chemical energy cards down. Sandra immediately expresses her disagreement for the two choices. Paul had decided to put a “wild” card down, meaning that he could make it substitute for any type of energy. Sandra expresses her dissatisfaction and states, “I disagree with that, because if it’s a wild card, you don’t have a picture to go along with it. Where is the energy going? Where is it leaving?” Even though she was not using the Rebuttal term here, she understands that there is no facts to support the assertion Paul placed publically for general acceptance by the group.

When Sandra is ready to play her hand, she has four pictures (a grill, light bulb, cell-phone, and Niagara Falls) (see Figure 6); and three words (radiant, mechanical, and electrical). Sandra places an energy transformation set down, which includes a picture of a grill, and the words “radiant” and “mechanical.” Jamie immediately notices this and asks, “What’s that?” Sandra replies, “An oven -- I mean a grill.” She then proceeds to claim, “Alright, so I have a grill... It’s radiant ‘cause of the light of the fire and then mechanical, because it’s going by itself.” Paul jumps in “How is it mechanical?” (Offering a rebuttal to her claim). Sandra questions her teammates and ask if, “Does it have to move?” Paul and James respond, “Yes its mechanical motion!” Trying to offer other backings, Sandra states, “Oh, I didn’t know that, I saw the wheels on the grill... Well, I can make...
it mechanical, because the heat waves are in motion.” Her group dismisses her claim, not only because she was wrong, but because she could not offer justified backings or grounds to support her claim.

Figure 6.

Explain

The level of engagement by students was paramount to any other activity we did involving energy. When students were brought back for whole group discussion, the teacher used this time to have them openly discuss their observations. The purpose of this part of the lesson was to assess whether students could make connections between energy types and how they lead to transformations and address any underdeveloped student ideas of the phenomena. The open class discussion started with having student groups share their claims that could be made about energy transformation from their engagement with UCG. Kim, the spokesperson for one of the small group, stated that her group realized patterns in determining energy transformations. For example, using an electrical energy card, she stated that their group realized a common misconception, in that electrons had to move from one object to another, for something to be considered electrical. This was important, because they noted that objects with no energy source (i.e. a TV that was unplugged), would not have electrical charges running through it and would not be classified as an electrical energy transformation. Such statements resonated across the five groups, yet in a few instances, students failed to see the patterns present in several energy transformations. In such cases, the teacher challenged students, using the same TAP framework to pose questions to rectify underdeveloped conceptions. In one example, Martha, the spokesperson for her group, gave an example of a hybrid electrical car being electrical to mechanical energy, leaving out chemical. The idea was underdeveloped because they had not acknowledged the energy present in the battery (which is stored chemical energy). By asking Martha’s group and the rest of the class, “When you wish to start your car, what’s needed to start?” the teacher challenges their assumptions that the car runs on solely mechanical and electrical energy, because it is a hybrid. This question sparked a heated discussion among students. Some groups were going back and forth, and Jason said, “you need a battery and without one, you cannot go anywhere. This is standard for all types of cars on the road!” Juan supported Jason and stated “with hybrids you need to plug it in first to charge the battery.” They eventually came to an understanding the first spark should come from the stored chemical energy in the battery.

Elaborate/Extend

After the teacher felt confident about students understanding about energy transformations, she asked students to construct their own UCG cards, in order to develop a deeper and broad understanding of phenomena. The teacher encouraged students to use what they learned from both small group and open class discussions. When forming their UCG cards, she reminded them to think of the following questions: “What do you already know?” and “Why do think so?” to guide and facilitate the construction of their
cards. This gave students an opportunity to become metacognitive about their learning as they reflect on their experiences while constructing their own cards.

**Evaluate**

The evaluation portion, summative assessment, of the activity concluded with a having students construct their own energy transformation Uno cards, applying the same rules as the teacher constructed game. This portion allowed teacher a chance to assess how students were able to apply new concepts and skills to the energy transformation card building activity. It is important to note that the teacher employed formative assessment strategies throughout the activity to monitor teaching and learning. For example, in the beginning of the lesson, students were questioned on their reasoning behind a hair scrunchie. Additionally, students were assessed during the lesson as the teacher walked around and monitored their conversations and their interactions with peers.

**The Value of the Card Activity**

In this study, students experienced an enormous conceptual shift in their ways of thinking. Previously students had been asked to be bystanders in the production of scientific knowledge, e.g., students were given a task to measure the potential energy of a ball, but this did not allow them opportunities to interact with each other and question themselves and others.

Van Zee and Minstrell (1997) describes argumentation as “group discussions in which students express their own thoughts in comments and questions rather than recite textbook answers; the teacher and individual students engage in extended series of questioning exchanges that help student articulate their beliefs and conceptions; and student/student exchanges involves one student trying to understand the thinking of another” (p. 212). In this activity, students created this open platform for learning, called reflective discourse and they did it through the use of argumentation patterns. The reflective discourse and argumentation patterns that were started allowed students an opportunity to become co-producers of knowledge. This was important because this activity opened the door to more purposeful in class discussions. In subsequent reflections, students had begun to express their styles of learning and preferred this manner. In one reflection a student made the following recommendation, “to make more lessons engaging I would play more learning games and I want to say that science is the best science class I ever had.” Another student stated that she wanted to return to “more card games, like the card game too. I like group activities, but fun games.” The conversation continued well outside of the classroom and came up even after the unit. Students continue debating on claims, backing and grounds they made weeks ago and still look for ways to come back and defend their defeated claim to their peers.

Lastly, it is crucial that teachers understand that conceptual development of scientific ideas does not happen in a short period of time such as one instructional hour. It is improbable to deduce that all students’ alternative conceptions were addressed in this short unit (Hewson & Thorley, 1989).

**References**


End Notes

i In this paper, we will use the term “alternative conception” instead of misconception.

ii The teacher described is the first author.

iii Because of limited space we will not discuss the meanings of these terms in detail. See Erduran, et al. (2004) for more information.

iv Pseudonyms are used to protect the identity of students.

WCPE 2012, Istanbul, Turkey
Physics Learning Instruments of XXI Century

Konstantin Rogozin, Department of Experimental physics, Altai State Technological University, Barnaul, Russia krogozi@mail.ru

Abstract

Along with the development of the humanity the teaching of physics passed four stages, each of them had its own physics curriculum and material carrier of knowledge: Pre-educational; Initial educational stage; University stage; Computer stage. At present, physics education is passing on to the next stage – Net stage. At this stage, there is an opportunity to transform radically both the content of teaching and learning instruments based on network multimedia. The following three aspects of creating physics learning instruments can be singled out: Information (knowledge itself); Technical (software); Technological (way of using knowledge and software). Information aspect. Up-to-date Internet technologies allow to structure physical knowledge in different formats using different software. Technical aspect. Up-to-date set of software allows creating learning instruments capable of demonstrating complex dynamic models and simulating real processes. Technological aspect. Global network learning instruments allow changing the emphasis shifting it from the “Push technology” used at the previous stages when teachers imposed their views on the phenomena and processes to the “Pull technology” providing independent active learning. As the result of the above, multimedia network instruments are able to create a special physical learning space where students: get a sufficient amount of information; are offered up-to-date computer instruments for decision-making; get physics competences through the use of new cognitive technologies. Network instruments of learning physics allow using all the Internet information resources accumulated by the humanity and learning physics using PCs, tablets and mobile phones at any place and at any time convenient for the student.

1. Introduction

Physics education has always been and still is the main engine of human development, including the humanities. We live in a transitional era - an era of constant change in the content and instruments of education.

Along with the development of the humanity Physics education passed four stages, each of them had its own physics curriculum and material carrier of knowledge. The first one is the Pre-educational stage (the Ancient East and Egypt, accumulation of basic knowledge about the world, the instrument of education was human communities). The next stage is Initial educational stage (Ancient Greece and Rome). In Russian, we call Annum Domini the “new era”. For me, the new era began in the year of 325 BC, in the year of Lyceum of Aristotle. Education, especially physical education, became a social phenomenon. In this stage the main process was schoolarization of education, in which the major teaching tool and information carrier was a teacher. University stage (Western Europe) is characterized by bookinization of education. At that time the language of modern science was created. It all started with the plus and minus signs (15th century). Descartes suggested the name of the coordinate axes. Newton created his Mechanics and Optics. The code systems for recording physics laws, tables and graphs were created. Books became a tool of education and universities were becoming its center. In Computer stage (highly developed countries) PCs are a tool of education (informatization of education). The development of physical education is the process of creation and improvement of physical process models. Computer technology enabled us to make these models dynamic. At present, physics education is passing on to the next stage – Net stage (whole world, netization of education). Network instruments for learning physics allow using all the Internet information resources accumulated by the humanity and learning physics using PCs, tablets and mobile phones at any place and at any convenient time. Multimedia network instruments are able to create a special physics learning space where students:

• get a sufficient amount of information;
• are offered up-to-date computer instruments for decision-making;
• get physics competences through the use of new cognitive technologies.
Education has a large inertia associated with the change of instruments, carriers of educational content and especially the teacher community. Our students are already at the highest stage, whilst most of the teachers still have to climb to it.

The strategic aim for learning physics is to give a chance to anyone to become a successful person. Physics is a game by the laws and rules. If you know them and follow them when you are making decisions, you are sure to get the correct result. Therefore the task of the teacher is to offer students the necessary decision-making instruments of the theoretical material and access to decision-making tool.

Physics content can be presented in the five following ways: concepts, formulas, theoretical problems, computer simulations and physical experiments. We discussed these in detail in our report at the Conference entitled “Cognitive test as a tool for physics learning,” the text of which is presented in this book. Each of these methods shape their own decision-making skills. Combined together, these methods form a physical competence. Therefore, we offer students networking tools for each of these areas separately.

I have been a professor of physics for almost 30 years. Students have not become better, but they have not become worse. They are just different. They are the next generation. They are the generation of computer games. So we have to offer them to learn physics in the form of playing an intellectual computer game. We have to offer students a variety of types of competitions/contests with themselves, each other and the computer.

One of these activities may be the creation of learning tools, such as training videos. In the fall semester of 2011 I proposed a competition for the best videos on the Hall Effect. Almost half of my students took part in this competition. Figure 2 shows screen shots of the videos created by the students. All the results presented in this article as examples were made by students and they were not amended, including the English translation.

Another type of games can be physics experiments. The students gather in teams of 2 or 3 and perform physics experiments at home. These experiments should be conducted without special experimental equipment, but with use of modern experiment software platforms for processing the results. The students together with the teacher then evaluate the original experiment and the laboratory report. Figure 3 presents the approaches to the determination of the free-fall acceleration value (screen shots of the video) and one of the students’ reports (.xls file) sent to the competition.
Now the general tools for learning and decision-making for students are PCs, tablets and mobile phones. Create training tools focused on the use of digital net technology and their introduction into the educational process is a task that remains to be solved.

2. Method

The following three aspects of creating physics learning instruments can be singled out:

- **Information (knowledge itself)**;
- **Technical (software)**;
- **Technological (way of using knowledge and software)**.

2.1 Information aspect

October 27, 2012 by typing “electromagnetic induction” into one of the search engines on the Internet both in Russian and English, I was able to retrieve more than 2 million answers. In both of these cases the same Internet resource appeared as the first result. It was Wikipedia. According to opinion polls, including those conducted at my university, rarely do students go to the second page of the search engine results. This means that the best information resources are not available to students. Today in the Internet, Wikipedia is the only available source of information. We must offer professionally made physics learning instruments to our students. Maybe they will be the second result straight after Wikipedia. In the first phase we have to offer students a minimum amount of specifically organized physics content. And this content should be accessible with the help of technical devices used by students.

2.2 Technical aspect

The technical aspect can be subdivided into two parts: It is **Preparation of representants of knowledge** and **Visualization of representants of knowledge**.

**Preparation of representants of knowledge.** In our opinion, further development of software has a commercial character, and is not for the users. We can create representants of any complexity with the standard package of Microsoft Office and MO for Mac. With these tools, you can create any fantasy. This can be done only with the professional knowledge of the aforementioned tools. After then the representants of physics knowledge are built using web technologies for educational tools.
Visualization of representants of knowledge. Effective teaching tools are determined primarily by how well they use the laws of cognitive psychology and psycholinguistics. Redish (2003) said that “to understand learning, we must understand memory - how information is stored in the brain” (p. 18). Here we have three major stages to consider. Sternberg (2006) stated “Encoding refers to how you transform a physical, sensory input into a kind of representation that can be placed into memory. Storage refers to how you retain encoded information in memory. Retrieval refers to how you gain access to information stored in memory” (p. 217). We have two input channels of information. Miller (2004) said “Input from the eyes and ears is first stored in the short-term sensory store. As a computer hardware analogy, this memory is like a frame buffer, storing a single frame of perception” The analogy of the human brain to a computer makes sense to identify the limit. (Card, Moran and Alan Newel, 1986), this is due to the ability of perception of visual symbols. First of all, the brain can not actively connect more than seven items at once (Miller, 1956). Second important feature is the ability of the brain to forget. Based on the experiments conducted by Ebbinghaus we have built the forgetting curve (Ebbinghaus, 1887).

![Figure 4. Screenshots of video on the Hall Effect](image)

The result shows that a few months later even in the case of simple and coherent mental constructs the memory can store the maximum of 5 percent of the original input information. This explains why (in our opinion) and the experiment carried out by four American professors of physics in the mid-nineties of the last century. They were teaching the same course in the Mechanics using various teaching techniques (problem-solving, experiment, theory and book without any changes and deviations). The mean scores of all the classes were the same within 1% for all the professors. Based on these results, David Hestenes (Taşar, Bilici & Fettahłoğlu, 2012) made a seemingly unexpected conclusion: “So, student scores were independent of the professor’s experience, teaching technique, or whatever...” (p. 148).

Apparently, he’s right if the teacher uses only one of these teaching techniques. Modern technical facilities enable students to use all of these techniques for training at any place and at any convenient time. It is the networking opportunities that the Internet provides us. In our opinion by the aforementioned teaching techniques of physics we should add one more technique. It is computer simulations of physical experiments.

Thinking is based on verbal information. Thought expressed in words is the beginning and the end point of the process of decision making. Use of different code systems make integration and organization of verbal information relatively easy (Sternberg, 2006). “They fill in gaps when provided with partial or even distorted information and visualize concrete aspects of verbal information.” (p. 244).
The use of different teaching techniques in the consideration of the same physical phenomenon will allow the new connections by integrating the new data into our existing schemas of stored information. Squire (1986) named this process the consolidation. It means a “process (Sternberg, 2006) of integrating new information into stored information” (p. 578). In humans, the process of consolidating declarative information into memory can continue for many years after the initial experience. This approach allows forming universal research skills as the components of metacognition, our ability to think about and control our own processes of thought and ways of enhancing our thinking (p. 221).

2.3 Technological aspect

- There exist only two technologies for learning instrument creation:
  - centric system (“PUSH”) technology;

In the first one the teacher is central in the learning process. He requires from the students to learn the knowledge which he expects from them. In the second, the students and the teacher are of equal magnitudes. They work together. The students and the teacher form competences acquired in mastering the World.

In our opinion, we can not require from the students to keep in mind several hundred formulas, definitions and concepts. But we need to teach our students how to find the necessary information to make informed decisions. Besides, we can teach them the effective ways of using this information, the way of systematic scientific inquiry.

The concept of «modeling cycles» was introduced to the academic community in 1995 by a group of authors, which was composed of the above named David Hestenes with colleagues (Wells, Hestenes and Swackhamer, 1995). The basis of their approach to teaching physics is the assertion that “in order to improve the quality of your students’ physics skills you need them to go through the same path of learning that took physics as the science of the study of physical phenomena.”

Modeling cycle involves three successive stages. The first of these is the allocation of the most essential aspects of the physical phenomena (usually physicists describe their physical characteristic), sufficient for its full description. The second stage is the definition of relations between selected parties (physical characteristic) and the definition of the boundaries of their changes. This is the stage to create a model of the physical phenomenon. The last step involves checking the created model of the physical phenomenon in practical action in the experiment. Using such learning algorithm, as the authors wrote in their publication, significantly improved the results of students.

3. Data and findings

The best way of learning is an active one. Using the Internet is by definition an interactive activity. When we were creating physics learning tools, we used the idea of “modeling cycles” and cognitive technology for contraction. We have created an educational resource which has a complex layered structure (currently there only exists in the Russian version) and includes: more than 3000 original author tasks; a full university course “General Physics” (in 3 parts); a short course (as a reference); 48 thematic presentations; 45 visual aids for lectures; lectures (in 8 parts); several hundred files containing additional information.
New technical possibilities suggest the need to create a new technology to be used in the educational process. Students are the future agents of the new technical and technological solutions for everyday life. As mobile devices (MID) become mandatory for the modern man, the orientation of the educational process to the above mentioned device is natural and understandable.

One possible way of organizing the learning process with the use of MID devices is a cognitive test. The cognitive tests are understood as the learning process in which we provide students with access to the content and decision-making tools. The offered content must be organized in a special way, and decision-making tools allow the teacher to evaluate the actions committed by students.

3.1. Cognitive content

Content for tools that use cognitive techniques requires a particular organization. For 2000 years of teaching and testing physics educators have accumulated a large amount of content. Decision making is always limited in time and content offered by the teacher.

This means that the teacher should present the content of physics in minimum volume of professionally designed set of documents, which were adopted by the scientific community. Each teacher provides physics courses in general physics in their own way. But due to the global modern educational process a document should be created consisting of the undisputed definitions, formulas, formulations of physical laws, which most teachers of physics would agree on. The idea was presented to our colleagues in private conversations at WCPE-2012. It was positively accepted with the colleagues ready to join the project after its launch. That is why from January 2013 at the Moscow State University a net resource called “Modern Physics” will be available. There, teachers of physics will be able to lay out their developments for colleagues. I will also lay out my version of the minimum physics curriculum.

3.2. Decision-making tools

MID allows Physical Content to be visualized in two ways: in real time or offline. The first way enables us to represent and control the four types of skills (using concepts, formulas, solving theoretical problems, computer simulation). An important feature of cognitive test of each task or group of tasks (depending on expediency) is a complete listing of situations that may arise in the study of physical phenomena with the opportunity to select one (more than one) of the possible. As an example, we show two pictures of the tasks on electromagnetic induction. In the first illustration students need to choose the right image, and the second to specify when aluminum ring will move to the right, left, or will not move at all. In Russia, we denote the north pole of the permanent magnet in blue and the red one represents the south.

![Figure 6. Two technologies of creation learning instruments](image)

Another example may be given in the section of computer simulation. In accordance with the assignment, students collect a scheme and then try to calculate the value of one of the physical quantities. The figure shows an applet created by a German teacher (Fendt, 2012). Using the proposed design (left) they were doing the scheme (right). Then students were measuring a current of one of the elements.
The teacher can not assess in real time the results of physical experiments conducted at home. In this case, after the experiment the students send the proof of the work (videos and lab reports made in Microsoft Excel) via MID device. The following is from the material sent to teachers. This is an example of the lab the aim of which is to determine the magnetic moment of the mobile phone. The measurements of the magnetic field of the students’ mobile phones were conducted using the method of tangent compass.

\begin{equation}
B = \frac{\mu_0 P_M}{2\pi} \frac{1}{x^3}
\end{equation}

\begin{equation}
k = \frac{\mu_0 P_M}{2\pi}
\end{equation}

Figure 8. Screenshots of students’ reports on Experiment of the determination of the magnetic moment of the mobile phone
The experimental data is constructed by students. The magnetic field of the phone depends on its position. According to the theory, this relationship is represented as a power of \(-3\). Mathematical treatment gives a 96 percent degree of certainty the power of \(-2.75\). The resulting formula is extrapolated to a few centimeters. The students concluded that while putting a mobile phone to one’s ear the magnetic field exceeds the magnetic field of the earth hundreds of times. Furthermore, for the same experimental data plotted on the position of the magnetic field in the degree 3. As a result, students have a linear relationship depending on the ratio of the calculated magnetic moment of the phone.

4. Discussion and conclusion

At the moment, two trends are noticeable in the use of digital technology. On one hand, there can be noticed a rapid replacement of personal computers by mobile devices. On the other hand, they become more powerful and increase their interactivity. We believe in a few years MID devices will be the primary means for getting information and decision-making. Students will be no exception to this. That is why my group is working on a project in which the best resources (content, video, computer models and so on) may be delivered to mobile devices. For the working title of the resource, we have chosen the name of the Physics Mobile (Figure 9).

The World Premiere of the Russian version is scheduled for August 20th at 2014. This is the polymodal multitask gadget-oriented networking physics learning instrument. Technical and technological issues have been resolved. But until August 20, 2014, we will not publish any articles about it, and will not even launch any part of the network. We’re just going to offer it as a complete learning solution. All Physics at once. Prior to that, we had come to agreement with all the owners of the best content. For the Russian segment of the Web we have already done so. We have all that we need. But it takes some time to finalize the project. Now we are looking for a place on the Web that will have the exclusive right to launch the instrument. And we’re looking for physics professors, with whom we’ll make English, German, French .... versions in 2014 – 2015.

Offering an opportunity to study distantly can not eliminate direct contact between teachers and students in the classroom. Antoine de Saint-Exupéry said “Il n’est qu’un luxe véritable, et c’est celui des relations humaines (P.25). (The greatest luxury in the world is the luxury of human communication – in my translation). That is why I want to finish this article with the last sentence of my speech at the conference. “Dear teacher, you are the best and the perfect tool for teaching students. But you have to prove it”
References


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Fear of Radiation: What can be Done

Pradip Deb, Discipline of Medical Radiations, School of Medical Sciences, RMIT University, Bundoora West Campus, Victoria 3083, Australia

Abstract

On average more than 6 mSv of radiation dose are exposed on us annually of which 3 mSv are from natural sources and 3.2 mSv come from manmade ionizing radiations. Ionizing radiations are widely used for diagnostic and therapeutic purposes and hence saving millions of lives every year. Although the radiation is so useful, the radiation issue is a long time global taboo. General public do not understand clearly the concept of radiation energy, effective dose and the effects of radiation on life and environment. The information about radiation transmitted via media (TV, newspaper, internet) is often biased and sensational which increases the public’s fear of radiation. To reduce radiophobia, radioactivity and their effects should be understood by the general public. One way to make the public more trusting of radiation issues is teaching radiation physics starting from the school level science education. In this paper I have investigated if teaching introductory topics on radiation physics can improve students’ understanding of key ideas about radiation. Elementary conceptions about radiations of 583 Bangladeshi students and 40 Australian students were tested by using a set of questionnaire before and after delivering a two hours lecture on introductory radiation physics. Students’ understanding has significantly increased after attending the lecture. This study shows that students’ understanding of radiation effects could be increased by introducing radiation physics in school level science curriculum and hence possible to reduce fear of radiation.

Introduction

From the beginning of formation of the earth, radioactive materials have been part of it. Long before the emergence of life the radioactivity and radiation existed on earth. Radiation is an important aspect of our daily life. We interact with radiation from several sources, both natural and manmade. Annually 3 mSv of radiation dose are exposed from natural sources and another 3.2 mSv come from manmade ionizing radiations (United Nations Scientific Committee on the Effects of Atomic Radiation, 2010c).

Ionizing radiations are widely used for diagnostic and therapeutic purposes and hence saving millions of lives. There are about 25 million people in the world living with cancer. Nearly 11 million people are diagnosed with cancer every year and more than 60% of them get curative and/or palliative treatment through radiotherapy or brachytherapy or nuclear medicine (World Health Organization, 2010).

About 14% of the world’s electric powers are generated from over 450 commercial nuclear power reactors in 30 countries around the world using radioactive materials (Karim, 2011). Although the radiation is very useful, the issue of radiation is a long time global taboo. General public do not understand clearly the concept of radiation energy, effective dose and the effects of radiation on life and environment. The concept of radiation is mainly transmitted by media (TV, radio, newspaper, and internet) especially after the occurrence of radiation accidents like Chernobyl or Fukushima. The information transmitted via media is often biased and sensational which increases public’s fear of radiation.

To reduce the fear of radiation it is necessary to make general public understand radioactivity and their effects. One way to make the public more trusting of radiation is teaching radiation physics starting from school level science program. In this paper, I have investigated if a 2-hour radiation physics lecture could improve students’ knowledge about radiation.

Background

Usage of Ionizing Radiations

Ionizing radiations are widely used in medicine for diagnosis and therapeutic procedures. Worldwide uses of ionizing radiations are rapidly increasing as new medical technologies are emerging. Radiography, mammography, computed tomography (CT), Positron Emission Tomography (PET), PET-CT, Fluoroscopy are
becoming routine procedures for diagnosis. In all of these systems ionizing radiations are used. Worldwide more than three billion x-ray exposures are made annually. In modern world about 920 x-ray examinations are performed per 1000 people per year (United Nations Scientific Committee on the Effects of Atomic Radiation, 2010a). In developing countries number of examinations per 1000 people is smaller, but as the total population is high, the total number of examinations is much higher than that of in developed countries.

The average amounts of radiation exposures from different diagnostic medical procedures over the world in the period of 1997 to 2008 are given in Table I. Data are taken from Refs. (United Nations Scientific Committee on the Effects of Atomic Radiation, 2010a, 2010b). The average annual dose is increased compared to the previous annual dose of 0.4 mSv per person for the period of 1987 to 1996 (United Nations Scientific Committee on the Effects of Atomic Radiation, 2010a)

Table 1. Average global radiation exposures from different medical procedures

<table>
<thead>
<tr>
<th>Medical diagnosis procedures</th>
<th>Annual number of examinations (millions)</th>
<th>Average annual dose (mSv) per person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic radiology</td>
<td>3,143</td>
<td>0.62</td>
</tr>
<tr>
<td>Dental radiology</td>
<td>380</td>
<td>0.002</td>
</tr>
<tr>
<td>Nuclear medicine</td>
<td>32.7</td>
<td>0.031</td>
</tr>
</tbody>
</table>

Annually about 5.1 million radiotherapy treatments are performed while teletherapy and brachytherapy treatment numbers are 4.7 million and 430 thousands respectively (United Nations Scientific Committee on the Effects of Atomic Radiation, 2010a, 2010b). Clearly medical uses of radiations are saving lives every day.

Nuclear power is an environmentally clean source of electricity. Nuclear plants in many countries are supplying about 14% to 24% of the total global electric power. Countries with huge natural resources can avoid nuclear power, but many countries with huge population and limited resources, like Bangladesh, will have to be depending on nuclear power plants to meet the demand of electricity in near future (Karim, 2011).

Risks and Fears of Radiation

Radiation has potential health risks. Ionizing radiation has effects on living beings. Many studies have been done and number of reports has been published on this issue. United Nations and its different organizations are continuously publishing reports for the public awareness of radiation effects (United Nations, 2011; United Nations Environment Programme, 1985; United Nations Scientific Committee on the Effects of Atomic Radiation, 2010a, 2010b). Radiation effects mainly depend on three factors - intensity, proximity and duration of exposure. If the amount of dose is high, the effects are also high. Close proximity to the radiation source will affect more, and the duration of exposure plays a key role in the radiation effects. Longer duration of exposure increase the risks. Radiation has short time and long time effects on human body. And also there are deterministic and stochastic effects. Induction of cancer due to radiation is a stochastic effect.

There are lots of other things that have risks for health and environment. But general public has a special type of fear for radiation. The word ‘radiation’ is perceived as a unique hazard (Bacher, 2003; Dauer et al., 2011; Wigg, 2007). It is mainly due to misrepresentations of radiations in media (newspaper, TV, radio, internet etc) and hence developing the misconceptions. Fictitious characters - Spider man, Superman, Incredible Hulk, Teenage Mutant Ninja Turtles etc. misrepresent the effects of radiations. After any radiation accidents like Three Mile Island, Chernobyl, and Fukushima, media transmit lots of information and stories - which are often biased and intentionally modified (Lijnse, Eijkelhof, Klaassen, & Scholte, 1990). When scientists admit their concerns about radiation - media turns them into facts (Associated Press, 2010; Dauer, et al., 2011; Ring, 2004; Szabo, 2010; Wang, 2009). Nowadays internet blogs are popular medium.
of transmitting concerns and opinions. Very often these opinions are biased. Recent discussions on blogs about Fukushima accident and the demand of complete shutdown of all nuclear reactors show the level of radiophobia in an extreme extent.

**Public Knowledge of Radiation**

General public are not comfortable with radiation. The public knowledge of radiation is often the results of the accumulation of the information gathered from the media. When there is a major radiation accident, public become alarmed for a short period of time about the effects of radiations. But they do not comprehend the properties of radiations and the effects of its doses on human body and environment. The 1987 Goiania (Brazil) incident is an evidence of lack of public knowledge about radiation (International Atomic Energy Agency, 1988). Four people died and more than hundred thousand people were exposed to radiation due to radiation illiteracy. Some studies reported about radiation illiteracy (Alsop, 2001; Culley & Angelique, 2010). However, the public awareness of medical radiation exposure is increasing gradually (Dauer, et al., 2011).

**Methods**

Several individual studies in different countries have been done to investigate students’ perception of radiation and radioactivity (Boyes & Stanisstreet, 1994; Colclough, Lock, & Soares, 2011; Cooper, Yeo, & Zadnik, 2003; Lijnse, et al., 1990; Millar & Gill, 1996; Prather, 2005; Rego & Peralta, 2006). Students participated in those studies have had some extent of radiation physics topics in their academic courses. So the question arise - what would be the students’ perception of radiation if they did not have any radiation topics in their academic courses? Would the perceptions be changed after radiation education?

Radiation physics is currently not included in school curriculum in Bangladesh. Students in Bangladesh encounter radiation topics for the first time in their graduate level physics courses. So Bangladeshi school students were chosen for this study. A survey was conducted to investigate Bangladeshi school students’ perception of radiation and radioactivity. A questionnaire (Q-A) was given to 583 students of secondary and higher secondary levels. Then a two-hour lecture on introductory radiation physics was delivered to them. After two weeks the same group of students were asked to answer another questionnaire (Q-B). The second questionnaire (Q-B) includes similar conceptual questions as Q-A. The student numbers and levels are given in Table 2.

**Table 2. Number of Bangladeshi student participants**

<table>
<thead>
<tr>
<th>Level</th>
<th>No of Students</th>
<th>% of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 7</td>
<td>130</td>
<td>22.30</td>
</tr>
<tr>
<td>Year 8</td>
<td>127</td>
<td>21.78</td>
</tr>
<tr>
<td>Year 9</td>
<td>92</td>
<td>15.78</td>
</tr>
<tr>
<td>Year 10</td>
<td>85</td>
<td>14.58</td>
</tr>
<tr>
<td>Year 11</td>
<td>82</td>
<td>14.07</td>
</tr>
<tr>
<td>Year 12</td>
<td>67</td>
<td>11.49</td>
</tr>
<tr>
<td>Total</td>
<td>583</td>
<td>100</td>
</tr>
</tbody>
</table>

As an initial study, only a particular geographical area in Bangladesh was covered. To have an international comparison, similar study was conducted in Australia among 40 first year university students who did not have any physics course before.

The questionnaire (Q-A) has two question sets. Question set 1 consists of 15 YES/NO type questions and question set 2 has 10 TRUE/FALSE/NO-IDEA type questions. Questions of set 1 & 2 are given in Table 3 and 4 respectively.
Table 3. Q-A Set 1 (for YES/NO response)

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Have you ever heard of radiation?</td>
</tr>
<tr>
<td>2  Have you ever heard of ionizing and non-ionizing radiation?</td>
</tr>
<tr>
<td>3  Do you know the difference between ionizing and non-ionizing radiations?</td>
</tr>
<tr>
<td>4  Have you ever heard of natural radioactivity?</td>
</tr>
<tr>
<td>5  Have you ever heard of radiotherapy?</td>
</tr>
<tr>
<td>6  Have you ever heard of nuclear medicine?</td>
</tr>
<tr>
<td>7  Have you ever heard of x-rays?</td>
</tr>
<tr>
<td>8  Have you ever heard of radiography?</td>
</tr>
<tr>
<td>9  Have you ever heard of computed tomography (CT)?</td>
</tr>
<tr>
<td>10 Have you ever heard of magnetic resonance imaging (MRI)?</td>
</tr>
<tr>
<td>11 Have you ever heard of gamma rays?</td>
</tr>
<tr>
<td>12 Have you ever heard of nuclear reaction and reactor?</td>
</tr>
<tr>
<td>13 Have you ever heard of nuclear power plant?</td>
</tr>
<tr>
<td>14 Do you think radiation has any effect in the human body?</td>
</tr>
<tr>
<td>15 Do you think radiation is safe?</td>
</tr>
</tbody>
</table>

Table 4. Q-A Set 2 (for TRUE/FALSE/NO IDEA response)

<table>
<thead>
<tr>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  People are exposed to several types of radiation every day.</td>
</tr>
<tr>
<td>2  All radiations have the same characteristics.</td>
</tr>
<tr>
<td>3  In medicine, radiation is used for diagnosis and therapy.</td>
</tr>
<tr>
<td>4  Radiations can both be useful and harmful to human life.</td>
</tr>
<tr>
<td>5  Radiation can induce cancer but can also cure it.</td>
</tr>
<tr>
<td>6  Radiation is used in industry, agriculture and energy production.</td>
</tr>
<tr>
<td>7  X-rays are not harmful.</td>
</tr>
<tr>
<td>8  A pregnant woman should not be subjected to x-rays.</td>
</tr>
<tr>
<td>9  Radiation doses delivered in CT are lower than doses delivered in x-ray radiography.</td>
</tr>
<tr>
<td>10 Radiation effects are the same for all living beings.</td>
</tr>
</tbody>
</table>

After collecting students' responses to questionnaire Q-A, a two-hour lecture on introductory radiation physics was delivered to the students. Ionizing and non-ionizing radiations, particulate (alpha, beta) and electromagnetic (x-rays, gamma rays) radiations, radioactivity, radiation dose, effects of radiation on human health, medical and industrial usage of ionizing radiations, radiation protection were discussed during the 2-hour lecture.

Two weeks later the students' understanding on radiation were tested by using questionnaire Q-B. There are 20 questions on Q-B, where first 10 questions are exactly the same as Q-A set 2 and the other 10 questions are new. Comparing the correct responses to the first 10 questions to Q-A and Q-B, the effects of teaching radiation on students' knowledge of radiation are evaluated. The responses to the new questions show the students' comprehensive ability. The 10 new questions in questionnaire Q-B are given in Table 5.
Table 5. New questions in Q-B (for TRUE/FALSE/NO IDEA response)

<table>
<thead>
<tr>
<th>Q</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Nuclear radiation pollute atmosphere.</td>
</tr>
<tr>
<td>12</td>
<td>Irradiation makes a person radioactive.</td>
</tr>
<tr>
<td>13</td>
<td>Irradiation and contamination are different.</td>
</tr>
<tr>
<td>14</td>
<td>Radiation has biological effects on human body.</td>
</tr>
<tr>
<td>15</td>
<td>Different living beings have different sensitivities to radiation.</td>
</tr>
<tr>
<td>16</td>
<td>The effect of radiation is independent of the organ absorbing it.</td>
</tr>
<tr>
<td>17</td>
<td>Gamma radiation is absorbed more easily than alpha radiation.</td>
</tr>
<tr>
<td>18</td>
<td>Gamma radiation is more densely ionizing than alpha radiation.</td>
</tr>
<tr>
<td>19</td>
<td>Gamma radiation is more penetrating than alpha radiation.</td>
</tr>
<tr>
<td>20</td>
<td>If an apple is exposed to radiation from a radioactive source and then the source is removed to leave the apple on its own, the apple will become a radioactive source.</td>
</tr>
</tbody>
</table>

Data and Findings

Students’ responses to the questions set in Q-A and Q-B are discussed in this section.

Responses to Q-A set 1

Percentage of affirmative responses of Australian (n=40) and Bangladeshi (n=583) students’ to questions in Q-A set 1 (given in Table-3) are shown in Fig.1. As radiation is not taught in their school, all of the answers are based on their knowledge gathered from media or other sources. The percentage of affirmative answers of Bangladeshi students to questions 12, and 13 are very high because nuclear power plant was a hot topic at that time in the media. 100% of the Australian students think radiation has biological effects whereas about 15% of Bangladeshi students do not know the effects of radiation on human body. Almost 100% of the students responded yes to question 7. Because x-rays are used in every treatment centers. But when answering question 8, more than 80% Bangladeshi students failed to relate x-ray and radiography. Responses to questions 9 and 10 show that most of the Bangladeshi students never heard of CT and MRI. But for Australian students CT and MRI are familiar as these facilities are readily available in Australia. Similar responses are found for questions 5 and 6 - radiotherapy and nuclear medicine respectively. Question 3 was very difficult for most of the students as more than 95% of them do not know the difference between ionizing and non-ionizing radiations. 80% or more Bangladeshi students and more than 60% Australian students do not think that radiation is safe.

All of the students surveyed in Bangladesh and Australia never had formal radiation education, but their overall responses to Q-A set-1 questions are significantly different (p=0.018). These differences are due to the difference between social structure and technological advancements.

Figure 1. Percentage of affirmative responses to question set 1. Series 1 indicates Australian students’ (n=40) responses, series 2 indicates Bangladeshi Students’ (n=583) responses.
Responses to Q-A set 2

Questions of set 2 are given in Table 4. There were 10 statements. Students had three options: True, False, and No Idea. The overall correct responses to these statements are given in Figure 2. For statements 2, 3, 6, 8, 9 and 10, most of the Bangladeshi students responded as ‘No Idea’ - showing that their ignorance of the radiation effects and various uses of it. It is surprising that about 90% Bangladeshi students responded wrongly to statement 7. They thought that x-rays are not harmful. Clearly they were not aware of the effects of x-rays on human body. They had used their perception of x-rays as they saw its uses in medical diagnosis. There is a significant difference (p<0.001) between the responses of Bangladeshi and Australian students.

![Correct Responses Q-A Set 2](image)

**Figure 2.** Percentage of correct responses to questionnaire Q-A set 2. Series 1 indicates Bangladeshi students’ (n=583) responses, series 2 indicates Australian Students’ (n=40) responses.

Significant number of Bangladeshi students indicated that they have “NO IDEA” about most of the radiation statements stated in the questionnaire. “NO IDEA” responses are very low among Australian students compared to Bangladeshi students. The “NO IDEA” responses are given in Fig. 3. More than 75% Bangladeshi students and 60% Australian students have ‘no idea’ about radiation doses in x-ray radiography and computed tomography (CT).

!["No Idea" responses: Q-A Set 2](image)

**Figure 3.** Percentage of “NO IDEA” responses to questionnaire Q-A set 2. Series 1 indicates Bangladeshi students’ (n=583) responses, series 2 indicates Australian Students’ (n=40) responses.

WCPE 2012, Istanbul, Turkey
Responses to Q-B

After collecting the responses of questionnaire Q-A, the students were given a 2-hour lecture on radiation in classroom teaching mode. Two weeks later, second questionnaire Q-B is given to the students to respond. 471 Bangladeshi and 23 Australian students responded. Overall perceptions have been improved significantly. The percentage of correct responses to the first 10 statements (the statements are same as Q-A set 2) are given in Fig. 4.

Figure 4. Percentage of correct responses to questionnaire Q-B statements 1 to 10. Series 1 indicates Bangladeshi students’ (n=471) responses, series 2 indicates Australian Students’ (n=23) responses.

There is no significant difference (p=0.12) between the correct responses of Australian and Bangladeshi students. It is the effect of teaching radiation for 2 hours. The improvement of students’ knowledge after getting radiation lecture is significant. The comparison of correct responses before and after teaching are given in Figs. 5 and 6 for Australian and Bangladeshi students respectively.

Figure 5. Comparison of correct responses of Australian students to questionnaire Q-A set-2 (series 1) and Q-B statements 1 to 10 (series 2). The difference is statistically significant (p=0.013)

It is evident from Fig. 5 that Australian students’ understanding of radiation properties improved significantly after teaching radiation physics to them. Radiation dose concept seems complicated, and needs more attention because it is very important for public to understand. The improvement of perception among Bangladeshi students are more significant (p<0.001) as seen in Fig. 6.
Figure 6. Comparison of correct responses of Bangladeshi students to questionnaire Q-A set-2 (series 1) and Q-B statements 1 to 10 (series 2). The difference is statistically significant (p<0.001)

The comparisons made here are among the responses to the same 10 statements. There is a chance that the students might have memorized the correct answers. To check this there are 10 new statements in Q-B. The students responses to those statements show their level of deeper understanding of radiation effects. The percentage of correct responses to statements 11 to 20 in Q-B are given in Fig. 7. There is no significant difference between the responses of Australian and Bangladeshi students (p = 0.599). But it is clear that the students conception about the statements 11, 12, 18 and 20 are not clear. Most students have misconception about nuclear radiation, radioactivity, irradiation and contamination. That is reflected in their responses to statements 12 and 20. Educators need to be cautious about this as it has direct impact on human life both biologically and socially.

Figure 7. Percentage of correct responses to questionnaire Q-B statements 11 to 20. There is no statistically significant difference between the responses of Bangladeshi and Australian students (p = 0.599).

Conclusions
The overall results of this study clearly show that the students’ basic knowledge of radiation is poor because topics of radiations are not included in their text books. Due to lack of proper source of information about radiation school students developed some misconceptions about the effects of radiation. They do not comprehend the risks (thinking x-rays are not harmful). When the students are taught topics on radiation, their conceptions about radiation improved significantly. During the recent Fukushima accident mass radiophobia was increased to a very high level. Internet blogs, social networks and media circulated
misinformation about radiation effects. If there were adequate information about radiation in the school text books it would be easier to manage the consequences arose from such incidents. Teaching radiation physics in schools is necessary, especially for developing countries like Bangladesh where uses of ionizing radiations are increasing and nuclear power will become major power-source in near future. If the students engage in activities that will allow them to understand how natural radioactivity is a part of our everyday environment and how radiation enters our lives in different ways, what are the effects of ionizing and non ionizing radiations in human health, it would be easier to increase the public knowledge. Hence prevention of radiation accidents and controlling the spread of radiation contamination will be easier.

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Science Teacher’s Class Planning at a Hospital School

Cristiano Mattos, Institute of Physics - University of São Paulo, Brazil
Luciani Tavares, Science Education Post-Graduate Program - University of São Paulo, Brazil, mattos@if.usp.br

Abstract

The action of professionals in education in hospital settings in Brazil takes place since the fifties. Currently, many researches are being focused on the pedagogical practices undertaken in these environments, particularly in the area of teaching hospitals. However, there is a lack of research that includes the teaching of science in these areas, even when we take a look on planning a lesson. Unlike the context of mainstream schools, the planning in the context of hospital schools no longer drive and gain new meanings through the demand of students who attend the hospital school. The teacher’s planning in the context of the hospital school is not just the action to prepare lesson plans, but also is in constant negotiation with the students of the contents to be taught. Therefore, this paper aims to analyze the organization of educational activity in the context of a hospital school and the implications for the redefinition of planning a lesson. As a theoretical basis, it will be used Activity Theory as an analytical tool of teaching. The choice and application of this instrument is justified by its focus on human development in the social, cultural and historical areas, in which individual action acquires meaning through the relationships that are established in the collective activity. Thus the present work is characterized as a case study of a hospital school in the city of São Paulo. To support the data that carried out this research, we used the transcripts of interviews with teachers who have worked and still work in the hospital school.

Keywords: Activity Theory, Planning, Hospital School, Science teaching.

1. Introduction

In the middle of the 20th century researches developed in Canada, England and United States started to portray prominently the concern with the hospitalized children’s psychological development. Beverly (1936) and Spitz (1945) (apud Fonseca & Ceccim, 1999) demonstrated that children’s internment period, even short or long, results serious problems for internment, mainly childhood children’s growth and cognitive development.

Later, in the end of the 1960’s studies were published contributing to modify the way children were treated during the internment period. Even more, those investigations generated propositions and interest on the hospitalized children care humanization, increasing the importance of the family visits during the internment period, the adaptation of the ambient space for the infantile service and the implementation of educational activities (Fonseca & Ceccim, 1999, p. 25).

Considering the Brazilian context, educators’ actuation in hospitals began in the 1950’s (Fonseca, 1999). However, only in the beginning of 1990’s the discussion about hospital classes and its regular legislation took place in Brazil, mainly in function of the promulgation of the Child’s and Adolescent’s statute (Brazil, 2004) that assures the constitutional right to education.

In the year 2002, the document “Hospital and Home Pedagogic Service - Strategies and Orientations” (Brazil, 20002) was published by the Ministry of Education and Sport assuring the educational attendance of children, youths and adults that stayed away from regular school due to long term disease. Then, the hospital schools have the responsibility to maintain student’s bond with the regular school through flexible and/or adapted curriculum guaranteeing the student’s entrance, return or reintegration to the regular school (Brazil, 2002, p.13). On the other hand, the lack of researches is verified in investigating physics teaching in these places. The worst problem is when we specifically consider how teachers plan their courses or classes.

In general, when we consider the planning in education activities, we do not think it as a continuous decision making process of future actions. Counter clockwise planning is typically understood as the final step before execution.
The continuous dynamic characteristic of planning clearly rises up at hospital schools. In that sense, the teachers’ performance in these situation evidences the online planning (Tavares et al., 2009). The online planning demands that both teacher and student base their interaction in a mutual perception of the ongoing situation at hospital. This is our main object of investigation in this work.

Taking in account this preliminary panorama, the present work has as objective the indentification of physics teachers’ planning organizing elements in the peculiar context of a hospital school. We deal with this case study, investigating how Physics teachers of the Mobile School/Specific Student (EMAE for short) made up their planning. The school is installed, since 2002, in the Oncologic Paediatric Institute (IOP-GRAACC), attached to the Federal University of Medicine of São Paulo (Brazil).

We are based on Activity Theory framework that was developed by Leontiev (1978), and later by Engeström (2001). Activity theory was casted because with this framework it is possible to propose a model of human activity in which, the educational activity can be represented by a hierarchical coordinated group of collective activities.

1.1-Theoretical background and research question

The Activity Theory was born at the old Soviet Union with the works of Vygotsky, Luria and Leontiev. These researchers looked for a socio-cultural-historic psychology, based on the Marxist philosophy (Duarte, 2002). In their works, Leontiev (1988) defines the term activity in the following way:

“Activity [in its generic sense] is the nonadditive, molar unit of life for the material, corporeal subject. In a narrower sense (i.e., on the psychological level) it is the unit of life that is mediated by mental reflection. The real function of this unit is to orient the subject in the world of objects. In other words, activity is not a reaction or aggregate of reactions, but a system with its own structure, its own internal transformations, and its own development” (Leontyev in Wertsch, 1979, p. 46)

Differently of the animal activity, in the human activity the direct relationship between the object and motive of the activity stops existing. In that way, a new complex structure of activities appears, established when the man started to live in society, with his/her consequent division of the work. In Leontiev’s (1978) classic example of the collective hunt activity of a primitive group of human beings, he exemplifies the complexification of the human activity structure through the differentiation between activity and action.

In the example, the human activity is composed by several coordinated actions accomplished by different individuals of the group. Among the actions is to produce the artefacts used during the hunt, to ascend and to preserve the fire to roast the meat of the hunted animal. The group could be divided in different categories. One of them could be the prey-waiters that would be waiting the prey in a pre-defined place. The second could be the beaters, responsible of previously frightening the hunt to the prey-waiters, in way to corner the animal and finally abate it. The necessary execution means to accomplish the action are called operations that depend of the conditions to achieve an end of an action. To the beater, the act of to run screaming and making noises are the operations that constitute the action of to frighten the animals. Then, the connections between subject’s action (beater) and the motive of the activity are the socially constituted relationships between him and the group remaining. That means that the subject’s action only gets meaning when he understands the relationship between the object of his action and the motive that permeates the whole activity.

In that sense the Vygotsky work was developed by Leontiev who took the activity as an unity of analysis. From the 1970’s this perspective was enlarged by Engeström that used activity as a system of activities, expanding Theory of the Activity. He carried out an exam of the systems of activities in the collective macro level instead of a personal or individual agent operating with the tools (Daniels, 2003, p.118). To deal with level of analysis Engeström introduced in the core of human activity the interrelations between individual and community through the insertion of rules (explicit or implicit rules), of a community (subjects that share the same object) and of the division of labour (community’s organization form that allows to reach a objective), besides the meditational tools, subject and object.

Engeström’s (2001) model points out the importance of the concept of internal contradiction as main characteristics that allows the transformation of the activities. Contradictions are driving forces among hierarchical levels of the human systems of activity. These contradictions generate dilemmas and conflicts that mobilize the transformation of the activity (Engeström & Sannino, 2010). Considering the educational
activity at the hospital school, contradictions were analyzed because EMAE constitutes a system of activities (student’s family, hospital and origin school) that are characterized by their particularities and different motives and ends established in the negotiation of the subjects’ interactions in his environment. Considering the theoretical framework our questions are: How do science teacher teaches at EMAE? How classes planning are made up in order to achieve the objective of the Science Teaching Activity?

2. Methodology of research

Data was obtained to support this research. We started negotiating an ethical agreement with Hospital’s Ethical Commission that allowed us to interview teachers and to make no video recording of students. We used a legal procedure to collect interviews data signing a consent form were all teachers were informed about the degree of confidentiality and the restricted public use of the recordings. This document has also the objective to inform the participants of the research to which institution the researcher belongs, the title of the work, the objectives and ends of the research, evidencing that his/her participation would be voluntary and that their personal data will be maintained in secrecy.

Semi-structured interviews were carried out with Physics and Biology teachers, who gave classes at EMAE. All interviews were audio-recorded and transcribed. We used Bakhtin (2006) as reference to interpret data, since the word in context is the most basic content of the human conscience. However the word is not seen as an individual action, but as fruit of social tensions. It is not enough to place two Homo sapiens together for the word to appear, they need to be socially organized, to share a social dynamics (Bakhtin, 2006). To Leontiev conscience is coupled to language through mediation that also connects language to social dynamics - activity. These interaction fields emerge on human activity, being one of the main objects of the Activity Theory.

To assess which teachers taught at EMAE we used school database at the hospital school. The coordinators helped us to cast science teachers from archives making up a list with the information contact (e-mail address) of those teachers for the period 2001 to 2009.

Starting from the initial contact with teachers, we casted 16 teachers from different areas of Science (Physics, Chemistry and Biology). From these total, the sample was constituted by nine physics teachers and one biology teacher.

3. Results

In this work we chose to make a cut in the general structure of the hospital activity. This activity is composed by different coordinated actions, with specific ends, which are composed by different operations defined by the conditions of work. When we consider hospital school activity as our unity of analysis, we could understand that EMAE’s activity emerges from other coordinated activities, for instance, the family activity objectifying to care for their son, the regular school activity (original school of the patient) objectifying students’ general education, and, dialectically, the hospital activity objectifying the cure of the patients. This coordination among different activities exposes numerous possible hierarchical levels, different forms of coordination of activities, actions and operations, which emerge in new hierarchical levels – complex system of activities.

Evidently, to consider all possible connection among those hierarchical levels in the analysis is not an easy task, if not impossible. Therefore, in this work we made a cut in this complex system, considering the part concerning teacher’s activity, more specifically, the science teacher’s activity. In that sense, the teacher’s activity is constituted of several actions and operations coordinated amongst themselves, amid them the action of planning.

Then, the analysis will be constituted by distinct moments. First, we will present the characteristics and peculiarities of the hospital school context, subsequently we will present some excerpts of teachers’ interviews, with the objective of identifying the elements that helped teachers planning classes.
4. Data Analysis

4.1-Characteristics and peculiarities of the hospital school

EMAE do not possess the characteristics of a conventional school. EMAE is submerged in a complex context, because teaching-learning activities happen in an atmosphere adapted to the appropriate student-patient conditions. That complexity is accentuated by the fact students are submitted to oncologic treatment, which is highly aggressive in a physical and psychological way.

Due to the long term highly demanding treatment for the patient, several of them interrupt their school life (Marchesan, 2007). EMAE has the objective to prevent the exclusion and the school failure, as a form of social reintegration and child’s and adolescent’s self valorisation, to offer conditions for the child to better understand his/her situation and condition, to recover abilities and basic contents, aiming to adapt the children to his/her school year origin as soon as possible and to maintain the bond with the child’s routine since the school was part of his/her daily universe and the school relationships were the space where she grew (Covic, 2003).

During project conception, where coordinators intend to insert the educational activity in the treatment of the student-patient integrating to other parts of the treatment, it was noticed that the students’ attendance should be done individually. They verified that each child/adolescent possesses individual characteristics and peculiarities, from micro-cultural differences such as neighbourhoods, cities or states, to different life styles and school experiences considering the treatment (Covic, 2003).

Therefore, the places and situations teachers teach vary a lot at EMAE. Among them the chemotherapy rooms, the playground, the internment rooms, the entrance lobby, BMT (Bone Marrow Transplant) rooms, in other words, in almost all spaces at the hospital.

The classes are registered in the school database and they are also filed in individualized student-patient archive. At the end of the class teacher registers the contents presented, how student-patient evolve during the class and all relevant events he sees as necessary to register. These files inform other teachers about the teaching-learning process of student-patients (Covic, 2003). These files are posteriorly sent to the regular school of the student-patient.

The registration process was organized by volunteers working at EMAE. Besides this function volunteers were responsible for other bureaucratic works such as the registration of new students and the first contact with the regular schools.

The student-patient files have a report with the evaluations that serves as an official document to be used by the regular school to decide on the student’s school year approval.

After the period of the classes teachers have daily meetings with the coordination of EMAE. During these meetings teachers comment on and discuss about the difficulties and doubts found during the classes, and they also discuss the contents taught to end reviewing the activities done during the day.

In addition to daily meetings, the hospital school implemented a formative and intervention teacher training course focusing hospital pedagogy. The project aimed to train teachers to deal appropriately with hospital classes (IOP-GRAACC, 2009). Teachers attended lectures and seminars on issues involving professionals working in the hospital – doctors, psychologists, social workers - and Education professionals - pedagogy teachers, mathematics, curriculum researchers etc.

4.2-The Activity to teach Physics at the hospital school and the action of planning

Starting from the aspects we presented, some elements of the structure of the activity could be pointed out. The activity of teaching physics in the hospital class is shaped by a diversity of actions, each one with its particular end guiding them. One of them is the action of planning the physics class that has as end to foresee how class will be. Likewise we can still say that this action is formed by several operations.

At the hospital school, the contents and tasks that will be used during the classes are defined just on the beginning of each class. Even deciding contents and tasks, teacher’s planning is constantly negotiated with the student-patient and with other hospital agents, as we can read on this teacher’s report:
“As time went by I was learning about the students, I didn’t go there just being her teacher, after all I got a certain intimacy and [began] talking as friend: ‘hi, everything fine? How are you doing?’ I was discovering from where they come from, what they liked to do, what they didn’t like to do, this that was nice for them. Then I began creating a space for them to say, ‘I am not enjoying the class’ or ‘I cannot understand it…’. Then I was trying ways that they feel free to criticize my class, to speak ‘I do not understand anything that you talking about’. Then I could try to find another way, until they express they have understood a little better. (Lucas)

Knowing the student-patient more intimately is a characteristic of the hospital school context. This informal conversation with the student is an operation that is part of the action of planning, which in turn is inserted in the activity of teaching physics at the hospital school. In other words, the casual dialogue with the student and the initiation of a more intimate relationship - to obtain information about the student, his/her origin, their tastes - facilitates the planning for the next encounter with the student. Another function of this kind of approach is give instruments to the necessary teachers’ flexible adaptation to articulate different specific contents sent by the dozen different regular schools.

Another operation of the planning action is to verify the student’s information file seeking, moments before the class, information on the contents to other teachers had already taught, is in this case, an operation of the action of drifting of the teacher.

“When I began [at EMAE], I gave a class that someone had already given. Not always I consulted [the students’ files], I used to ask students at the beginning of the class. It didn’t consult because I thought it was just take the textbook and everything will be okay. But then, you leave the [daily] meeting and you discover that two other people gave class to him. Then I began to check the file.” (Matheus)

Considering the teacher’s report, to look for information in the files about the contents already developed wasn’t part of his/her initial planning, even if he was conscious that he could do. In other words, students’ files verification was still in the level of actions composing the most general activity of teaching at the hospital school. Only after sharing information during the daily meetings, with other teachers and coordinators, Matheus linked the object of his/her action with the reason that permeates the activity as a whole. In that sense, the teacher reorganized his activity of teaching physics, and the students’ file verification that before was in the level of the actions became an operation of the action of planning.

Let us pay more attention to the daily meetings that happen after EMAES activities were finished. In general, interviewed teachers tell that these meetings are fundamental in several different aspects, according to transcription below:

“The meetings always began with the coordinators talking; discussing a little about the day, speaking about some administrative need and later on we began [talking]. It is when meeting in itself began, when each teacher begins speaking about whom he had given class, if there is a new and if he is a new patient just arrived, then we used to talk about the boy’s situation, and if we had a file to fill … Then we used to talk about the content we taught, if some student had difficulties, and if a relevant situation to be informed. We always discuss student’s cognitive or physical difficulties. I think that what was interesting, and we always discussed, if one [student] was taking some treatment, some chemotherapy or some medication that had some side effects... because the student doesn’t speak. If he can’t take the pencil he doesn’t speak about, if he can’t see he say nothing. Then the teacher has to have the sensibility to notice that. If the teacher will give class for some student that is taking a medication or he has some side effect, if he loses a little of his vision ... then the teacher that goes there should already knows and he will give a hint if some other teacher goes there. Then if he already knows he should be prepared to not be indelicate with the situation, and he must be already prepared to write larger letters or to give another activity to not embarrass the student... That was things we usually did and I think those meetings were fundamental for the work proceed in the way we wanted. In the beginning I didn’t understand it, but later in the course of time [I did].” (Juliet)

Through Juliet’s report, we can detach some aspects of the daily meetings at EMAE - teachers changing information among them and with the coordination, pointing out the difficulties found during the classes. Let’s take the example of the action of filling student-patient’s files. Teacher should write down in the student’s file the contents worked during the class and the observations he/she considered relevant about
the student’s behaviour during the class. This procedure of registering the class into the file is another operation of the action of planning. This action have, at the same time, the objective of registering the given class and pointing out information to the other teachers in future classes. In this case, the teacher can go on articulating strategies considering each student’s specificities, for instance, the use of larger letters for students with visual deficiency, as described in Juliet’s report.

Another identified aspect emerged with the interviews, as already commented, are the meetings and lectures accomplished during the “Course of Improving”. Teachers revealed that they attended lectures given by several professionals that work at the hospital. The themes of the lectures are the cancer types, forms of treatments and medical procedures. They also had lectures with researchers form Education touching themes as curriculum, methodology, teaching conceptions, mathematics, among others.

One of the most cited subject was the procedures with student-patients at BMT rooms. Teachers detached the objective of the lecture where they discussed the importance of the hygiene of the equipment used in the hospital ambient.

“In the beginning they were many teachers talking about pedagogy, or then doctors talking about the cancer. We had a class about washing the hand that I found incredible... on hygiene... that was incredible: oh god! It’s true! She [speaker] showed things about hygiene, she talked about contamination; she spoke a lot of things. [...] And she spoke how we should wash our hands ... I thought it was important. Indeed you don’t have a lot to ask, you should ask the nurse. How do I wash my hands? Sometimes she doesn’t have time to teach you. In my second day of work the coordinator took me to BMT [Bone Marrow Transplant], and he asked me to clean like this and that {moving his hands}. He gave me instructions, but he is not a [medical] professional speaking. And her [speaker] was there and she spoke. Sometimes you enter with a pencil and you thinks, ‘it is just a pencil ant has been little used’. But at same time it is dangerous.” (Matheus)

The action of hygiene hands and materials are part of the community’s routine that works at hospital (doctors and nurses), but to others coming from outside (volunteers, teachers and family) this procedure should be learned, and to the Physics teachers it should be part of the teacher’s planning, mainly when you should plan timings of a class. For instance, when the teacher gives classes in the BMT rooms, he should follow certain procedures before beginning the class. First, he/she should wash the hands, to clean the materials (pencil, eraser, drawing board), to use the apron and the hair bonnet. Only after these procedures the teacher can come near the student and give the class. However, the teacher attributed new meanings for the hands hygiene after the lecture of the professionals of the hospital, as the report transcribed above. He turned this action into an operation of the action of planning.

5. Final considerations

Here we evidence the complexity that involves the teachers’ performance in hospital, specifically when we have a closer look to the teacher planning activity at the hospital school. In this context, planning stops being something previously organized, developed until its execution, and become one of the continuous actions of the teaching activity. Teachers pointed out the importance attributed to the meetings after the period of classes and also the lectures they had at “Course of Improving” given by hospital professionals. Those lectures gave them instruments to articulate this information contributing to a better teacher daily class planning. This online planning demands the teacher to be flexible to deal with the unpredictable events such as medical interruptions of the class, physical difficulties of the students-patients and even a continuous negotiation of the epistemological, ontological and axiological aspects of science.

This work is part of a bigger one where we are exploring comparisons between hospital science classes and regular science classes. Considering specifically the subject of Science it is very clear that the axiological dimension (Why do we teach Science? What is Science for?) get an enormous importance in an ambient like the Oncologic Paediatric Institute. The meaning of “give classes of Science” to children with this kind of disease made teacher reflect about the meaning of science to the lives of these boys and girls as we can read at the exert above:
“Nor all of the educators, but some feel very well in that kind of work. Physicists, Chemists, Mathematicians, we suffer a lot. Because we are used to thirty shouting students in the classroom. Then you scream that it [the content] will be on the exams, this is still traditional. But once in a while to control the students screaming, unfortunately that is what works. But I noticed that inside GRAACC we can’t do that, isn’t it? We can’t do that there. In the beginning I didn’t know discern it, now I know. When I will give class I needed to make the guy to like to have class. We did not get the point just teaching the Newton’s law or an equation of second degree to him, it not works. What meaning does have that for these kids? The kid is sick, taking chemotherapy, vomiting, with pain! Why will I speak for him that \( x^2 + 2x + 3 = 0 \) are interesting?” (Juliet)

Then the question of the finitude of our lives becomes one of the major problems teachers must deal affecting viscerally the planning activity at hospital school.

References


Context- Based Physics: Case-Studies of Teacher Training and Materials for Science Education in Road Safety Education

Alessandra Mossenta, Research Unit for Physics Education University of Udine, Italy and Regional Office of Friuli Venezia Giulia, Ministerium of Education, Italy
Marisa Michelini, Research Unit for Physics Education University of Udine, Italy
Alberto Stefanel, Research Unit for Physics Education University of Udine, Italy
Laura Tamburini, Regional Office of Friuli Venezia Giulia, Ministerium of Education, Italy

Abstract

The role of context in learning (that is contextualized) and motivation (that arises in context) implies a need of designing, promoting, revising the physics learning integrated into social issues. Road safety education should be the ground to build conceptual knowledge as well as the context of meaning for the safety rules. Good examples of activities related to context-based physics pointed out a need to study how the conceptual knowledge of physics can be built in science & society contexts, thus grounding a new way of looking at the setting of both physics and science & society. This innovation in the way to look at contents to activate effective teaching-learning processes needs adequate teachers formation. Many dimensions are involved in this process: teacher professional development, ways to teach physics in different contexts, design-based research, proposals design. A research was planned to address these levels, founded in the methodology of Inquired Based Learning and in the Model of Educational Reconstruction as a framework for the re-structuration of the physics content in the proposals, the issue of the motion in its levels of both description and aspects relevant to active and passive safety in the mobility. Formative activities were offered to schools, involving in two years 40 kindergarten and primary/middle school teachers of different subject areas, interested in road safety education. We analyzed the process activated in teacher education and the teachers’ works during the formation and in their experimentation in school. The main value emerges from the integration of the competences of teachers in treating problems about traffic safety in different topics and the researcher competences in scientific education. The main results concern good practices as suggestions for curricula innovation, alternative proposal integrating learning of both scientific and safety aspects in new contexts and promoting student motivation, improvement in teachers’ PCK.

Introduction

There are several perspectives in which the link between context and scientific learning could be considered. Research pointed out that learning is contextualized (being shaped by the phenomenological context of learning) and that motivation for learning implies the personal involvement of students, that occurs in context (Lave 1988, Taasoobshirazi & Carr 2008). Scientific concepts should be built in familiar contexts for students: subject content related, everyday life, socio-cultural contexts (Euler 2004, Michelini 2005, Duit 2009) to address the challenges of building meanings for the concepts and motivation for learning. It is increasingly necessary to include a large context for scientific learning, to provide to the students opportunities to build and shape their learning. From the educational point of view this implies a need of designing, promoting, revising the physics learning integrated into social issues as a way of improving the students’ scientific knowledge and their acknowledgment of the role of science in society and everyday life. In this perspective road safety is a context where the scientific concepts play a crucial role as keys for understanding phenomena, risks, safety rules.

Students’ learning studies pointed out that in certain learning contexts (such as the issue of energy) physics concepts are evoked but they do not take the value of conceptual knowledge. What has the role of reference, evocation, application should be the ground to build conceptual knowledge in physics as well as the context of meaning for the safety rules. Good examples of activities related to context-based physics education, also concerning traffic and safety were proposed (Waltner, Wiesner and Rachel 2007; PLON, 1986; Parchmann, Luecken, 2010; Duit, Mikelskis-Seifert and Wodzinski, 2007). These projects pointed out that there is a great need to study how the conceptual knowledge of physics can be built in science & society contexts, thus grounding a new way of looking at the setting of both physics and science & society, not as evoked context.
but based on the fact that subject knowledge is built into it. This innovation in the way we look at contents to activate effective teaching-learning processes needs adequate teachers formation.

The Pedagogical Content Knowledge of the teachers (PCK, Shulman 1986) must be developed to allow them to introduce effective teaching for their students; the joint design of the teacher as researcher with the researcher is the basis for a real change in teaching. Innovation is essential: the context where subject content learning develops is changed and the subject content related knowledge becomes conceptual knowledge in the context of social issues. Therefore it becomes an innovation centered on learning in unusual contexts, in which the teacher is required not only for a new design of the learning proposals but also for a new way of looking at the subject matter content. On the other hand there is the contextualisation of learning, that requires the personal involvement of the student. Innovation should offer conceptual and manual operativity of the student that the teacher should make her/his own and put in the new learning project. Many dimensions are involved in this process: teacher professional development, ways to teach physics in different contexts, design-based research, proposals design.

A research was planned aiming to address these different levels, with the following research questions:

How is it possible re-organize the physics contents in the context of traffic safety to produce motivation and effective learning? Which are the effective ways to promote the professional development of teachers in teaching and integrating scientific topics and the related traffic safety? How teachers modify the proposal coming from research to implement it in contexts different for level, topic treated, style?

In this work we present and discuss the formative process activated, the new proposals offered to the teachers during the formation, the materials produced by teachers and how their design work was grounded.

Methods

Our research was carried out into a broad educational context involving the issue of road safety education. An activity was offered to teachers of primary/junior high schools of Friuli Venezia Giulia Region (North East of Italy), as part of a Project to promote road safety education in the school context, referred to as “SicuraMENTE” (that is, “safely”). In the first two years of implementation of the project 40 teachers of different subject areas attended the formation, in two steps (one in each year). In the second year also kindergartner teachers were involved. The Project was grounded on a first pilot activity carried out in Trieste, the capital of the Region, in 2008/2010 as a partnership between the Research Unit in Physics Education of the University of Udine, the Faculty of Psychology of the University of Trieste and the Regional office of the Italian Ministry of Education, Universities and Research (MIUR-USR).

Our planning developed concerning both the materials (contents and teaching strategies) to be offered to the teachers for their class activities and the structure and the features of an effective teacher training. With regard to the materials we assumed the Inquired Based Learning (IBL, McDermott et al. 1996) as a teaching method, with strategies based on the exploration of the contexts in which formal physics quantities are built, and the Model of Educational Reconstruction (MER, Duit et al. 2005) as a framework for the re-structuration of the physics content in the proposals. We chose for dealing the issue of the motion, in its levels of both description and aspects relevant to active/passive safety in the mobility.

We planned the teacher formation according to the Physics Education Research (PER) outcomes (Duit 2006, Mossenta et al., 2010, Michelini, 2003, Corni, Michelini and Stefanel, 2003). As a first step of the teacher formation the physics learning knots related to the proposed content were discussed, as a framework for the scientific perspective in the context of road safety education; then, curricular proposals were analyzed as suggestions, reference for innovation in the teachers’ autonomous design. Specific apparatuses and proposals were experienced by the teachers, who performed the same conceptual paths to be proposed in their classes and become more confident in performing the hands on activities proposed to overcome the learning knots and to build the meaning of the concepts. After this phase, teachers’ ideas and their first educational proposals were discussed with researchers and peers to build a final proposal suited for each teacher’s class. Each planned activity was then proposed to the pupils and its outcomes were discussed, starting from a “report” of the teachers, also to plan future activities. During the formation the teachers were introduced also on methodological aspects related to the framework of the project and to
a constructivist perspective of the development of the knowledge, specifically focusing on: the role of everyday life experience and of the experiments in building the scientific knowledge by pupils, the pupils’ spontaneous ideas and the need to introduce scientific ways for a description and an interpretation of phenomena, the role of peer sharing of ideas in building new models, for a gain in a scientific view of issues linked to the road safety education that could enable pupils to give a sense to the road safety rules. In our perspective, proposed to the teachers, road safety education is considered a context where scientific knowledge is developed, to build and/or to increase the pupils’ scientific skills and tools able to give a sense to the safety rules. The process of increasing pupils’ involvement proposed - and experienced also by the teachers in their formation - was to face the phenomenology with successive steps of observing, recording, knowing, recognizing, interpreting, giving sense to the rules. We suggested to the teachers a perspective of integration of the road safety education issues into their teaching subjects as a way to enhance the impact on the students of the road safety education issues and as a motivating factor (for the interest that a social topic would raise) for their subjects, as a starting point to enhance the level of specific knowledge.

The proposed physics contents were organized according to self–sustaining proposals, selected to offer some core aspects concerning both the physics subject matter and the road safety rules. This structure made possible for the teachers to select for their class activity only one aspect or more, in a global framework where the topic of the motion was considered from the points of view of its reading (from a perception and common sense based reading of it to a scientific view) and of its management (on the road, with the wheels and the other people, to understand the risks). During the formation 3 proposals were offered to the teachers involving simple apparatuses and on line sensors measurements (Figure 1). Proposal 1 is specifically devoted to a description of motion: a conceptual grounding for the role of a frame of reference is built from a need of description of an individual’s position (in 3/2/1 dimensions), teaching the role of a map; after the activities devoted to the introduction of position (as a vector quantity), the description is then enriched with displacement, velocity, acceleration; the need to take into account the time is introduced by passing from the description of the positions to the description of motion as a changing of positions during a trip; graphs s(t) and v(t) with a tape timer and a motion sensor are introduced as tools for the description in one dimension after a connection between a description in 3/2 dimensions and the corresponding study of motion in one dimension realized by the principle of composition of motions. This proposal embeds the pupils’ specific context in their learning process: for example, the need of a compass (and its role) emerges to give a global orientation to the “local” map of the classroom; or, aiming at a description of students’ positions in the classroom, emerges the need of a frame of reference with an origin and two (or three) oriented directions. Proposal 2 is devoted to collisions: sensors for motion and force measure the force while a little car crashes after a falling down on an inclined plane: speed and mass are changed to show the role of momentum in collisions; safe distance, involving the different reaction times, emerges as a necessity to avoid crashes and the different variables influencing it are studied. Proposal 3 is devoted to friction and grip: friction before and during the motion is measured for a bicycle wheel and for a toy-car using sensors or an hand-made meter in different ground and mass conditions. Sliding and rolling friction for a wheel normal to the ground or inclined are measured, to show their role in starting and bending.

Figure 1. Laboratory activities during the teacher training concerning the different proposal offered in the training course: starting from left: Proposals 1, 2, 3
Each proposal was offered during one session of experiments and discussed in another session; each session lasted 3 hours. Before and during the class implementation also individual sessions were carried out with the teachers to refine their plans, adapting them to each specific class, adding activities or solving problems not previously taken into account and arisen during the activity.

In the second year of the Project, when also kindergarten teachers were involved in the formation, proposals 1 and 3 were offered to the teachers, enriched with more activities specifically devoted to the building of the concepts: in proposal 1 particular care was given to the basic competencies needed to describe motion (the concepts of oriented direction and intensity as a pre-knowledge for describing motion by vectors, position, displacement and trajectory); in proposal 3, the analysis of the different types of friction and the parameters affecting it were analyzed with a cluster of experiments.

Data and findings

In the first year of implementation of the project 30 primary and middle school teachers attended the training course; 30% of them projected activities introduced in their classes. During the discussion between researchers and teachers for projecting activities in their classes the teachers organized new paths, starting from the proposals introduced in the formation. The suggested topics were: 1) study of momentum conservation in one and two dimensions collisions; 2) role of center of mass for equilibrium for bodies on systems changing their speeds, as pupils into a braking bus; 3) study of friction as an aspect of the interaction between surfaces in contact and its influence on motion; 4) aspects of a bicycle: study of the role of the gears, of the brakes....

Primary school teachers (5/30) preferred to plan activities involving proposal 1 (description of motion, building and using a map) to be implemented in the next school year, 2011/12; middle school teachers (4/30) preferred to plan activities involving proposals 2 and 3; 2 of these teachers implemented the planned activities with pupils during the last part of the school year. In the second year (2011/2012) kindergarten teachers (2/30) planned and implemented activities concerning the first steps of proposal 1 to develop the students abilities needed to learn the concepts of position, displacement (with their vector nature), trajectory; primary school teachers (5/30, 3 of them involved in the teacher training only since this year) projected and implemented the activities linked to the proposal 1; middle school teachers kept on the activity following the same planning as before. The plans of the primary school teachers of the second year included some activities involving friction (proposal 3) but the teachers focused the class activity on the proposal 1 and planned to develop the issue of friction the next school year. In both years the teachers introduced new experiences (and materials) near to their usual teaching subject, adapting them to the proposal, avoiding sensors as tools for their class – activities, even if they had experienced their use in the formation: they did not feel confident using them in their first class activity.

As case studies we propose some features of the planning of the teachers.

A physical education teacher in Middle School (Case study 1) carried out an activity in two classes, composed of pupils aged 12-13. He suggested the approach: a question in a pupils’ brainstorming, arisen showing some sport shoes and bicycle and motorcycle tires, about the reason of so many kinds of shoe soles and tires. The activity was a study of the interaction between the floor and an object moving on it, to answer to the previous question, and the scientific inquiry was proposed as the way by which simple emerged pupils’ observations (“The kind of floor/the grip is important to answer”), would become explanations by an understanding of the role of these factors. The first pupils answers comprised words related to an everyday life context (the kind of floor, wood or grass or mud...) or to something known by the media (as the use of the English word “grip”, learned from motor races commentary). During this brainstorming they did not clearly distinguish between the factors influencing the phenomena and the interpretation of it, nor used any term linked to the scientific explanation. The class activities were planned to introduce the pupils about the role of the floor/ground in the motion, to formalize it by the scientific concept of friction, then to find the factors affecting it, first in sliding, then in rolling, focusing on the starting and on the stopping of a straight motion and finally studying the bending. After the activity the pupils used scientific terms to describe/interpret situations of interaction between the floor and something moving on it, and (according to the report of the teacher) they performed better in physical education because they had learnt the
process of movement as an interaction between the floor and the moving person. The teacher planned the experiments to show the role of the contacting surfaces (kind, size), and of the weight in sliding and rolling friction, using mattresses for the physical education activity, balls and bars, carpets (Figure 2). The experiments managed during the formation constituted a reference to look at and not a just a model to copy.

Figure 2. Steps of the activity with pupils using mattresses to explore friction (Case study 1)

Then he exploited a set of equal bicycles that the school devoted to outdoor activities and speed meters to perform some qualitative experiments showing the role of the speed and of the gears on the stopping distance and the possibility of crashes (Figure 3).

Figure 3. Stopping distances using rear brakes at two different speeds, 15 km/h (left) and 20 km/h (right): activity performed by middle school pupils.

A teacher of technological education (Case Study 2) carried out the activity in a first class of middle school, with pupils aged 11-12. Starting from the proposals of the formation and suggesting the context of the home-school round bus trip, he proposed to the pupils to study the role of an accelerated reference frame in the description of phenomena and in their interpretation. Particularly interesting here is the focus of the proposal on the braking bus, but for physics and the possible related risk. In the first phase of his planning he did not take into account the learning difficulties in physics, and the possibilities coming from an active role of the students. After a survey of the concepts needed for the activity emerged the need to relate the definition of center of gravity given to the pupils by the math teaching of triangles to its meaning in physics. As a co-planning result, the aim of the educational path was the exploration of the role of the center of gravity for the equilibrium, to exploit it then to understand what can be observed on a braking bus. The teacher proposed to the pupils to find the center of gravity of a slab of wood, first on the base of the symmetry of geometrical systems, then, after the recognition of students’ difficulties on this point, with an experimental search on “bi-three dimensional” objects with a regular/non regular shape, including the pupils themselves (Figure 4).
The teacher followed the same teaching method also in an exploration of the role of mass distribution on the equilibrium of an object/pupil on a braking bus: he proposed a first experiment with laboratory equipment, an articulated parallelepiped provided with a plumb line hanging from its center of gravity and a mass added at different heights; then he transferred the previous outcomes to a pupil, reproducing the situation on a braking bus bending himself forward and changing the kind of contact surface between floor and pupil’s shoes to explore the role of friction (Figure 5).

The teacher was very surprised for the final claim of a pupil, “when the bus suddenly starts, it is as if I were still on a carpet and somebody pulled it forward”, focusing the issue of the different description (and interpretation) of the movement in different frames of reference in a manner that the teacher didn’t foresee as possible in a pupil’s answer.

In the second year of the Project a kindergarten teacher (Case study 3) carried out the activity with 15 pupils of 3-4 years old. The teacher selected and enriched the concepts proposed in the course. She embedded in her teaching plan some activities about the concept of direction (pupils’ walks, in a common direction and in opposite directions) and about the concept of length, position (as a vector), trajectory, displacement. She followed an input emerged during the co-planning discussion: she used as teaching method storytelling and role play, then games for an exploration of the space realized by the pupils’ bodies (moving as a worm to experience the straight trajectory, as a snake to experience a curved trajectory). She proposed to the pupils a role-play activity where they were the characters of a tale, “Little yellow cap” of B. Munari (a contemporary version of Grimm’s fairy tale “Little Red Cap”), concerning also traffic and traffic lights. To perform the activities she proposed a model of a real context, a town, realized by cushions of simple shape (cylinders, cubes, parallelepipeds) labeled with pictures. In pupils’ walking across the town, role-playing the tale, they experienced the concepts of position, displacement, trajectory. The teacher realized a context of meaning for abstract concepts with real objects, made simple representative mediums both for the real world (in 3 dimensions) and for some abstract concepts: wool threads on the floor marked directions, floor or cacao power under the pupils’ feet marked the trajectory, the pupils’ body represented oriented directions (with one raised finger). Concerning road safety, she proposed traffic light and its colors meanings. These activities produced a great learning in pupils on the meaning of trajectory, direction, remaining open the knot of the orientation of this direction. (Figure 6).
Figure 6. Kindergarten pupils’ activity for experiencing the same direction (left) or the same length in different directions (center) and storytelling (right)

Two teachers (case studies 4-5) in primary school (both non-science teachers) proposed the same activity in 2 classes of 41 pupils 10 years old. They organized a large exploration of the school surroundings (in space and time), including several subjects (physics, geography, languages, history...). They adapted several activities proposed in the course into their design: the role and operation of a reference frame; the role of friction for moving. They could exploit some ancient maps of the land near to the school, showing the structure of the small villages where the pupils were living, to compare with contemporary maps and with the actual place, explored and represented by maps drawn by the pupils. The need of a common frame of reference and the subsequent introduction of the role of the compass arose among the students when they wanted to perform a comparison between the maps and to communicate information about them. A review about a recent trip allowed the pupils to describe it by a coordinate system or by positions and displacements as vectors, distinguished from the trajectory they had followed. A comparison between the role of the ancient road system and the contemporary one (with more vehicles on the road and higher speeds than in the past) made clear the need of the safety rules to avoid crashes (and, more generally, of a traffic policy with a planning aiming at a matching between the road users needs and the environmental needs). The historical development of vehicles and the role of the wheel was the stimulus for focusing on exploration of friction to understand its role on the (vehicle) motion, following an approach similar to the one experienced during the course, of changing one feature at a time to explore its role. The materials for this section of the activity were suggested by a science teacher, colleague of the two non-science teachers who attended the course, and was only begun in class for the little time remaining at the end of the school year (Figure 7).

Figure 7. Ancient maps on contemporary maps of the pupils’ villages (left) and pupil’s map (center); activity about friction (right) performed by pupils 10 years old.

The teachers involved other experts in their project, to obtain a support on each aspect they considered. The activity followed the path proposed in the course, but applying it to the school village and its surroundings well known by the pupils.

Two teachers (both non-science teachers) in primary school (case studies 7-8) proposed activities planned together (including peer education) to one class of 25 pupils 11 years old (last grade of Primary school) and one class of 17 pupils 6 years old (first grade). They organized two specific contexts taking into account the past experiences of pupils also in road safety education (particularly for the older pupils) and the geography of the surroundings of the school (particularly for the younger pupils). They introduced pupils to the need of a reference frame and the use of a compass for describing positions and movement when
offered to the pupils the challenge to explain something to younger pupils of their schools (peer education towards school mates): the older pupils suggested an activity of simulation of a road circuit (built in the garden of the school) where younger pupils had to show an adequate behavior (as a pedestrian or as a vehicle). The map of the circuit was the object where the need of a scientific communication of the positions emerged; the planning of the circuit asked to the pupils to take into account the meaning of the road signals and rules and the physics of the motion. The pupils of the first class of Primary school planned (aiming at improving kindergarten pupils’ knowledge of the environment of their future school) to use storytelling (about a little trip they made in the surroundings of their school) and a model of the village with both the school buildings and where they had performed the trip. The task to put the model in the right orientation and the need to explain to the younger pupils the trip gave to the pupils the cue to introduce a frame of reference, starting from a local one (origin in the school gate, first choice of an oriented direction the one of a river near it) and arriving to a global one using a compass. Then they chose to tell the trip to younger pupils, to introduce them to the description referring to a frame of reference and to the road signals (and their meaning) in the surroundings of the school, to show them how they will have to behave the next school year (Figure 8).

Figure 8. Activity of peer education with a game on a self-made circuit (left) and with a model of the village (right).

Both teachers followed a very similar path, one of them considering more road safety education than physics, the other performing more experiments, according to her better attitude in doing experiments.

Discussion and conclusions

Research on learning processes pointed out the central role of contexts and the need to deepen the studies about the ways to link them with learning. We made an hypothesis of development of scientific knowledge building it into social contexts, as a way to build the scientific meanings. We focused on the topic of motion in the context of road safety education and carried out a formation activity involving 40 teachers, from kindergarten to middle school; 30% of them experienced the proposed activities in their classes. We analyzed the process of teachers’ professionalization and the materials produced starting from the proposals offered in the course. The following outcomes emerged.

All the teachers involved in the project modified the proposals experienced during the course, in different perspectives: concerning contents, new topics were introduced particularly in middle school (role of the brakes and the tires, center of gravity...), with a social perspective, as a need towards pupils (to avoid crashes); developing basic pupils’ skills integrated in social needs to enhance pupils’ level of comprehension and expression of their environment, particularly in kindergarten and primary school. These teachers embedded the proposed activities in very large contexts, eventually with a careful selection of the aspects of the proposals to develop (kindergarten teacher). These teachers had as a reference for their planning the cognitive level of their students.

WCPE 2012, Istanbul, Turkey
As for proposals, also the materials for the activities were the outcome of adapting school resources or building new tools devoted to the class activity. In this effort middle school teachers used materials taken from the field of their usual teaching, employed in new ways. The other teachers introduced materials from everyday life and involved pupils in developing them. We regard these new and context related versions of experiences as an effect of the teachers’ involvement in the learning proposal, and when it was difficult, as in the case studies 4/5 for studying friction, the teachers were able to involve in their activities other expert colleagues. Even if the activities of the primary and kindergartner teachers were not strongly subject related, they are more developed in the area of interest of the teachers, a literature area, and less in scientific area. We regarded as a cue of the importance of the teachers’ professional background the fact that no one teacher planned to use sensors in the class activity, preferring to spend time in building apparatuses not simple. Perhaps the gains using ITC have to be proposed in a manner more embedded in the context.

Referring to our Research Questions, we state the following.

The role of physics contents were to give answers to problems emerged from the contexts chosen by teachers in their experimentations, derived from their personal contexts and experiences: the different kinds of shoe-soles, or tires (friction, interaction, motion), the maps of the classroom, of the school, of the town (local and global reference frame; direction), the bicycle; a reconstruction of the contents in different un-usual contexts was obtained via the collaboration between teachers as researchers and researchers in designing proposals able to address the students learning knots about physics concepts as well as traffic safety (RQ1).

The teachers modify the proposals of the course, enlarging the proposed activities, adding contexts related to the class level and their specific teaching subject (RQ3): kindergarten teacher creating specific learning contexts (the room where position, trajectory, displacement could be explored, recognizing the role of reference system) and using differentiated strategies and methods (i. e. storytelling and role play); primary school teachers, realizing very rich contexts using a lot of possibilities offered by the country (i. e. the map of the school, the orientation of the map in a global reference system; the games outside the school; the integration with different disciplines); teachers of middle school, inserting the physics contents in their usual activity (i. e. the study of the friction in the physical education palextra), converting the activities experienced during the teacher formation labs in activities carried out with the didactic materials usually used for different aims and topics.

The main contributions of the formation (RQ2) were of providing exempla specifically designed integrating PER and the traffic safety context (making explicit the cultural value of the proposals); then, of providing examples realized in pilot classes (winning the difficulty to change perspective); moreover, of proposing experimental activities concerning the topic to be experienced by teachers (realizing a resonance between formation and experimentation), able also to overcome typical learning difficulties; finally, of discussing with teachers the project to be implemented in classroom and suggesting modification in progress, arriving at discussing the experimentations results in terms of evaluation of the progressions in their PCK.

The main added value of the teachers plans and implementations emerges from the integration of the teachers competences in treating problems about traffic safety in different topics and the researcher competences in scientific education. Different content subjects were inserted and proposed to pupils in new contexts, creating motivation, integrated learning of both scientific and safety aspects, improvement in teachers’ PCK, good practices as suggestions for curricula innovation.

Two future perspectives can be seen for this work: a study about the possibilities to implement activities devoted to a teaching of scientific procedures, introduced but not specifically addressed in this activity; a study about the possibility to develop the contexts proposed to introduce teachers in the use of ICT (sensors, but also other devices) to obtain a better teachers’-professionalization in terms of skills in introducing new teaching tools and strategies.
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Project-Based Learning And Ideas at the Bosepo as the Unique Students’ Competition in Sarajevo

Merve Kevser Coskun, Bosna Sema Educational Institutions, Sarajevo College, Bosnia and Herzegovina
Zalkida Hadzibegovic, University of Sarajevo, Faculty of Science, Bosnia and Herzegovina

Abstract

Students involved in the BOSEPO project based on learning science presented their knowledge gained in science, mathematics, computer science and modern technology as well as their scientific skills. Bosna Sema Energy/Environment/Engineering Project Olympiad (BOSEPO) has been opened to high school students, as an innovative science competition, is the only science project competition organized in Sarajevo, Bosnia and Herzegovina (BiH) in order to implement student’s ideas and contributions in finding the best solutions for better living. 300 high school students participated in the three BOSEPO fairs and competitions, and were leaded by 85 science teachers. They created more than 200 projects in four different fields: on science, engineering, technology, and on computer science knowledge and skills integration. The outcomes of BOSEPO are a better understanding of science by participants, a better preparation for their study at undergraduate (university) education, participation to the project competitions at the international level and collaborative work among students using project based learning pedagogy.

Keywords: high school, project based learning, science education, student’s project

Project-Based Learning and Ideas at the BOSEPO as the Unique Students’ Competition in Sarajevo

Introduction

Learning environment of secondary school students in Bosnia and Herzegovina (BiH) is mainly traditional, lack of demonstrations, experiments and student’s active role. There are several reasons for dominant teacher-centered teaching/learning physics at secondary school level. The most important reason is the lack of more enthusiastic instructors who should provide an active learning environment in physics education based on hands-on experiments, or usage of videos, mobile devices, laptops and other modern technology devices which are owned by great number of students. Many other physics pedagogy variants known throughout many physics education research journals and book references could be also applied for making physics education of BiH a modern and trendily one. We witnessed that an active role of students who learn science by project-based learning (PBL) activities allow them to be involved in a scientific environment as the Bosepo fair and competition as a unique event for students, their parents, friends, and also for their science teachers.

Literature Background and Research Focus

In the stories by Katherine Bagley (2012) has been presented ten expressions of high school students who were the country’s most brilliant young inventors with their plans after a successful science fair participation. They showed how their preparing for science projects helped them to meet the opportunities for their future occupations such as their prestigious university enrollment or a company inventor’s involvements for receiving the invention licenses. Such very complex set of benefits that high school students could have from a science fair and competition might be a pathway for many science educators to understand how any personal and active students’ PBL involvement can be very affirmative, valuable, and a successful engagement in the development of science fair projects.

In some countries there is a strong tradition of science fair organizing. The United States held the first students’ science fair in 1928 (Bellipanni & Lilly, 1999) so that many of participants during nine decades could produce more positive attitudes towards science learning throughout science fair. Casey Murrow
(2010, p. 15) highlighted the importance of students’ communication and collaboration as an explicit value of the science project fair and competition because “students are learning from each other while also contributing ideas or questions to classmates and friends”.

Joseph Krajcik and his colleagues (1998) have shown in their research results that PBL is important in for the inquiry process in science education that is now for new generations a central educators’ mission to educate in many dimensions of culture, economy, politics streamlines that each society needs to meet in 21st century for their sustainable development. Mettas and Constantinou (2006) found that university-school partnership for organizing students’ fair on science and technology have the opportunity to create university openness for high school students who can be stimulated in science and technology problem solving and “decision making as important life skills”.

Science projects can be used as “a mechanism for promoting scientific skills with an emphasis on learning” (Mettas & Constantinou, 2007). Preparing students by manners of the process in order to develop their skills by identifying issues in real life environment; formulating questions and finding solutions by doing research and interpreting data could bring a new generation much better prepared for their future role in society as key actors of its development and real existence. Some findings by science education research results show that PBL, science fair activities and science and technology education need to be implemented to enhance understanding of fundamental principles of science for actual and future practice in different school education programs on science.

In practice there are many different ways of PBL implementations. If it is conducted at an institutional level (large-scale implementation) or in a course or classroom (small-scale implementation) it is a useful concept of education (Lehmann et al., 2008). The main learning principles are headed for four learning characteristic: (1) cognitive learning, (2) interdisciplinary learning, (3) active learning, and (4) collaborative or team-based learning (de Graaff & Kolmos 2003). BOSEPO is the only PBL organized at institutional level in BiH, and we recognized it as an opportunity to explore such concept of education for reaching evidences of its outcomes and benefits that bring them in BiH education. Beginning from the first BOSEPO held in 2010 both authors and organizers started to collect data that can be used on research purpose.

The BOSEPO data are collected in two different ways. Main sources of data are the data used by BOSEPO organizers and commissions. In these data collections are the most important data about number of students, number and type of students’ completed applications, number and structure of jury members, the jury assessment results, the lists of BOSEPO prizes and winners, and data about further BOSEPO winners’ participations at the international level of several world wide projects’ competitions. Second data sources are the BOSEPO Questionnaire based data collections taken directly from the BOSEPO participants. The BOSEPO Questionnaire 1 was created by researcher (Z. H.) during the first BOSEPO event and implemented later for the last two BOSEPOs. This questionnaire brought the first views about who the BOSEPO participants were, and what were their attitudes according to some general questionnaire questions which encouraged researchers for a new questionnaire creation in future.

BOSEPO Description

Bosna Sema Project Olympiad (BOSEPO) is an innovative science fair opened to BiH high school students. The BOSEPO’s mission is establishing a high school environment for focusing on science, mathematics, engineering, computer technologies and environmental issues, in an effort to provide a world-class education in public. The BOSEPO participants have been included in the learning process based on creating ideas and models on science, math and computer science. Students apply their knowledge in a scientific method that is required by the basic arrangement of the BOSEPO Commission. The main purpose of BOSEPO is to provide an opportunity to young people to understand the problems of sustainability of life on the planet Earth so that they can contribute in finding the best solutions for better living.

BOSEPO has been organized for students of the schools within Bosna Sema Educational Institutions. Bosna Sema Educational Institutions form a private educational system in Bosnia and Herzegovina, furthermore Bosna Sema schools involved in Bosnia and Herzegovina educational system at state/entity level of administration. International Burch University (IBU) from Sarajevo has recognized the quality and importance of BOSEPO science fair and competition. IBU has hosted and been a golden sponsor of BOSEPO.
It is the only Science Olympiad in Bosnia and Herzegovina based on PBL. BOSEPO student projects are divided into three scientific categories: Energy, Engineering and Environment and they are also classified as juniors (primary school level) and seniors (high school level). Students presented their projects not only individual but also in groups, which is consist of two members for the valuable prizes. The most interesting prizes for participants are two awards: (1) the IBU full scholarship for undergraduate studies, and (2) the international participations of the awarded students by BOSEPO Commissions who compete with their projects at the international project competitions in several countries in Europe, Asia and America.

High school students and senior, primary school students have been confronted using their knowledge and creative thinking to prepare following BOSEPO application elements.

1. Project abstract (the first step in project selection by the BOSEPO Commission).
2. Project journal (written document about student’s project ideas and work with recorded results as they are produced).
3. Research paper (written in English, with all required sessions as a cover page, table of content, abstract, introduction, used material and implemented method, the achieved results, discussions, acknowledgments and references).
4. Project products (poster, experiments, devices invented, and other proofs presented in own journal including students’ research paper)

Project exhibition is a final event at the BOSEPO fair and competition in the university environment (IBU Sarajevo).

BOSEPO Participants Assessment

Students’ projects have been under very strict assessment by the BOSEPO judges who were members of the academic community from several universities in BiH. Students receive up to 10 points for completed project according to one point for each of ten criteria presented in Table 1.

Table 1. Judgment Criteria of the BOSEPO Established Student’s Research Project by Individual or Team

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity/Originality</td>
<td>considering the originality of the ideas; uniqueness of student’s approach</td>
</tr>
<tr>
<td></td>
<td>to solve an issue at the level of sustainability</td>
</tr>
<tr>
<td>Review of Literature</td>
<td>research of scientific literature and use of references</td>
</tr>
<tr>
<td>Scientific Thought</td>
<td>statement of hypothesis; clarity of purpose; identification of all relevant</td>
</tr>
<tr>
<td></td>
<td>variables</td>
</tr>
<tr>
<td>Scientific Method</td>
<td>evidence of depth of study and effort in employing scientific procedures,</td>
</tr>
<tr>
<td></td>
<td>and proper methods followed for experimentation and investigations</td>
</tr>
<tr>
<td>Data Management</td>
<td>proper data recording and display in tables, charts, and graphs, and</td>
</tr>
<tr>
<td></td>
<td>proper analysis of data</td>
</tr>
<tr>
<td>Conclusions</td>
<td>drawing logical conclusions, consistency of conclusions with obtained</td>
</tr>
<tr>
<td></td>
<td>data, and recommendations for further research</td>
</tr>
<tr>
<td>Applications</td>
<td>practical applications of the project, and benefits for society in certain</td>
</tr>
<tr>
<td></td>
<td>ways</td>
</tr>
<tr>
<td>Research Skills and</td>
<td>level of skills and effort by each student as researcher to</td>
</tr>
<tr>
<td>Understanding the Project</td>
<td>student understands each step of project implementation</td>
</tr>
<tr>
<td>Quality of Display</td>
<td>well organized display and contribution in own project journal</td>
</tr>
</tbody>
</table>
Research questions

Two main research questions are:

RQ1: What information do BOSEPO participants’ data show?

RQ2: How are they involved in PBL and projects’ preparations?

Answers to these particular questions were found in data collections from two above mentioned data sources.

Methods

BOSEPO Participants

The 222 BOSEPO participants who were included in research came mostly from four Bosna Sema schools of Year 1-Year 4, and aged 13-19 years. Only 15 of them were from the group of talented elementary school seniors. They worked on the 149 project idea developments using their prior knowledge, and knowledge gained during projects’ preparation time, and guided by their science teachers as their supervisor/mentor.

Research Instrument

The BOSEPO Questionnaire 1; as a main research instrument consists of 11 questions divided into three categories: 1) yes/no questions (two questions), 2) multiple choice questions (six questions), and 3) open-ended questions (three questions). Two open-ended questions reflect on the number of hours spent on project preparations at school and home. The third open-ended question is a question that provides answers about appropriate scientific fields of physics which knowledge is applied in students’ projects.

Research Design

This pilot study started in 2010 by collecting data from organizers for preparing the basic descriptive BOSEPO statistics and using data by Questionnaire 1. The Questionnaire 1 has been applied for three BOSEPO exhibitions held in the IBU building (January 2010, January 2011 and February 2012) in Sarajevo, Bosnia and Herzegovina. Participants gave answers to the 11 questions voluntarily and anonymously.

Results and Discussion

The BOSEPO Descriptive Statistics and Discussion

The first BOSEPO was organized in January 2010 at the international level. Participants came from high schools included in the educational system structures similar to the Bosna Sema Educational Institutions in BiH. It was an excellent event and a great opportunity for numerous participants to meet each other in Sarajevo as their host city. BOSEPO 2010 participants were from 15 countries and three continents (Asia, Africa and Europe). Well known world economic crisis to all of us, and other problems related to travel from distant BOSEPO participants’ countries, were main reasons for organizers to make a decision that BOSEPO starting in 2011 would become a competition that is organized only for students from Bosna Sema schools. Participants of BOSEPO 2010 were presented 58 different project ideas by 78 students under the leadership of 30 mentors and in front of 15 jury members.

The 300 participants realized 207 projects ideas in the three BOSEPO. Most of the projects were on engineering project category (42%), and then 31% are on the energy, and 27% on the environment project category. At the first BOSEPO competition students were from different countries, but at the second and third were only from Bosnia and Herzegovina. Therefore, only the data and results on two BOSEPO competitions held in 2011 and 2012 have been presented in this paper. According to the data presented in Table 1, it is evident that pairs are the most number of collaborative working groups (more than 80% of participants). Significantly number of females is larger (over 50% of participants), especially in BOSEPO 2012 (74% of female participants). Participation of students by category of projects is different in 2011 from the one in 2012.
Number of projects was notably increased at the last BOSEPO that covered the environmental topics. This is a remarkable fact as the BiH education system does not include any subject of curriculum which strictly considers the environmental themes at high school level. On BOSEPO 2012 was 15% more participants than on BOSEPO 2011, but there were an increased numbers of jury members (almost in double), and the number of advisors (science teachers as students’ mentors). Basic statistical data used here have been taken from the BOSEPO data collections that BOSEPO organizer (Bosna Sema) holds, and shown in Table 2.

Table 2. Descriptive BOSEPO Statistics of the Sample

<table>
<thead>
<tr>
<th>Sample description</th>
<th>BOSEPO manifestations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BOSEPO 2011</td>
</tr>
<tr>
<td>Number of students</td>
<td>N=94</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>42%</td>
</tr>
<tr>
<td>Female</td>
<td>58%</td>
</tr>
<tr>
<td>Working group</td>
<td></td>
</tr>
<tr>
<td>Individual</td>
<td>14%</td>
</tr>
<tr>
<td>Pair</td>
<td>86%</td>
</tr>
<tr>
<td>12-14</td>
<td>19%</td>
</tr>
<tr>
<td>15-16</td>
<td>38%</td>
</tr>
<tr>
<td>17-18</td>
<td>42%</td>
</tr>
<tr>
<td>19</td>
<td>1%</td>
</tr>
<tr>
<td>Number of projects</td>
<td>53</td>
</tr>
<tr>
<td>Project category</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>21%</td>
</tr>
<tr>
<td>Environment</td>
<td>28%</td>
</tr>
<tr>
<td>Engineering</td>
<td>51%</td>
</tr>
<tr>
<td>Jury members</td>
<td>15</td>
</tr>
<tr>
<td>Mentors/Advisors</td>
<td>20</td>
</tr>
</tbody>
</table>

It is very important to note that a significant increased number of students who were attracted by the BOSEPO manifestations that can be seen as a much larger number of realized projects from the 54 projects in 2011 to the 96 projects in 2012.

Figure 1. BOSEPO 2012 fair and competition environment at the IBU. (http://infima.ba)

The Results and Analysis of Questionnaire 1

The Questionnaire 1 data revealed that 88% of students had developed personal project ideas. Table 3 shows responses to the yes/no questions. Students generally gave affirmative answers to the first question (Q1: Did you develop your personal project idea?). Two BOSEPO 2011 participants did not give any answer.
Table 3. Distributions of the YES/NO Answers.

<table>
<thead>
<tr>
<th>Question</th>
<th>YES BOSEPO 2011</th>
<th>YES BOSEPO 2012</th>
<th>NO BOSEPO 2011</th>
<th>NO BOSEPO 2012</th>
<th>NO answer BOSEPO 2011</th>
<th>NO answer BOSEPO 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>88%</td>
<td>79%</td>
<td>10%</td>
<td>21%</td>
<td>2%</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>58%</td>
<td>86%</td>
<td>41%</td>
<td>14%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Quite a large number of the BOSEPO 2011 participants (41%) gave a negative answer to the second question (Q2: Are you able to explain your project idea using physical/science laws?). On the other hand, a large number of the BOSEPO 2012 students was higher in the project idea creations as well as increasing the capacity to defend own ideas using their knowledge in physics in comparison with students’ answers on BOSEPO 2011. Responses to the Q4 and Q5 (questioning about the number of working hours at home and in school respectively) are very different. Some students worked on their projects from one to 200 hours. For about 14 hours students spent at home to prepare their BOSEPO projects in 2011, but BOSEPO 2012 participants spent 15 hours on average working on the projects. Students spent an average of 12 hours during in-school working on the BOSEPO 2011 for projects, but on the BOSEPO 2012 projects students spent more than double (26 working hours). Students’ responses have been categorized into three groups of responses according to the number of working hours spent (Table 4).

Table 4. Distribution of Student Groups According to Working Hours

<table>
<thead>
<tr>
<th>Students’ Group</th>
<th>BOSEPO2011</th>
<th>BOSEPO2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working at home</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I Group (1 – 5) WH</td>
<td>46%</td>
<td>51%</td>
</tr>
<tr>
<td>II Group (6 – 10) WH</td>
<td>31%</td>
<td>20%</td>
</tr>
<tr>
<td>III Group (&gt;10) WH</td>
<td>23%</td>
<td>29%</td>
</tr>
<tr>
<td>Working in school</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I Group (1 – 5) WH</td>
<td>8%</td>
<td>23%</td>
</tr>
<tr>
<td>II Group (6 – 10) WH</td>
<td>76%</td>
<td>54%</td>
</tr>
<tr>
<td>III Group (&gt;10) WH</td>
<td>16%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Note: WH = working hours.

Around 50% of students spent between one to five working hours to make their projects prepared for the assessment and exhibition. It could be assumed that students were not able to accurately know the number of project working hours. Only few of them who worked in pairs gave different contribution evidences, but mostly they had a similar distribution of duties on the mutual projects measured in WH.

The most frequent answers to the Questionnaire 1 questions are presented in Table 5.

Table 5. The Most Frequent Answers to the Six Multiple-Choice Questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer BOSEPO2011</th>
<th>Answer BOSEPO2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q3. Did your teachers help you for developing your ideas?</td>
<td>YES (51%)</td>
<td>YES (45%)</td>
</tr>
<tr>
<td>Q6. Your BOSEPO project participation will be important in your future career. Please mark one option:</td>
<td>Very important (53%)</td>
<td>Important (59%)</td>
</tr>
<tr>
<td>Q7. Your choice of university study will be one among following</td>
<td>Engineering (34%)</td>
<td>Environmental physics (36%)</td>
</tr>
<tr>
<td>Q8. Your expectation on BOSEPO grading qualification is:</td>
<td>Honorable (55%)</td>
<td>Honorable (50%)</td>
</tr>
</tbody>
</table>

WCPE 2012, Istanbul, Turkey
The differences in the students’ responses according to their participation on BOSEPO 2011 and BOSEPO 2012 are clear according to the Q6, Q7, and Q11 answers (Table 5). It is noticeable that the BOSEPO participants of the last competition showed more interest on Environmental Physics not only as a project’ topic, but also as the preferences of their future studies at university. Not so great, but there is a difference in students’ selection of persons about who their audience will be for talking about the BOSEPO competitions, going from their friends (BOSEPO 2011) to their classmates (BOSEPO 2012).

Expected answers content to the ninth question (Q9: subject of applied physics in your project are (e.g. mechanics, optics, environmental physics...) are some form of a brief explanation about knowledge in physics that is needed and applied for the project ideas implementation. Students’ answers are not denoted by sentences, answers are described with only one or two keywords (mostly mechanics and biophysics).

Students did not provide a brief asked explanation about the necessary field of knowledge to carry out project ideas and project realizations. Such chosen keywords are presented in Table 6. It can be considered as a confirmation of students’ interdisciplinary learning, understanding, and doing on modern science. Here is a very visible shift from only three significant fields to the seven fields that has covered projects’ topics and needed knowledge for it (Table 6).

Table 6.

Answers in the Form of One Keyword that Denotes Their Physics Knowledge

<table>
<thead>
<tr>
<th>Answer (keyword)</th>
<th>BOSEPO2011</th>
<th>BOSEPO2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>51%</td>
<td>5%</td>
</tr>
<tr>
<td>Physics</td>
<td>28%</td>
<td>20%</td>
</tr>
<tr>
<td>Environmental studies</td>
<td>21%</td>
<td>9%</td>
</tr>
<tr>
<td>Environmental physics</td>
<td>39%</td>
<td></td>
</tr>
<tr>
<td>Biochemistry</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>Biophysics</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Computer science</td>
<td>3%</td>
<td></td>
</tr>
</tbody>
</table>

BOSEPO 2012 participants included the fields of physics (biophysics, environmental physics), and other interdisciplinary fields of science (biochemistry and environmental studies) that are not disciplines taught at high school level. These choices could be explained as a significant improvement of students’ needs of knowledge and their efforts to learn more outside of the high school curriculum.

BOSEPO Winners at International Competitions

BOSEPO winners have been participated at the International Sustainable World Energy Engineering Environment Project Olympiad (I-SWEEEP) held in Houston, Texas, USA (in 2011 and 2012) bringing in BiH the gold medals for their successful science projects. For example the I-SWEEEP 2011 gold medal winner was a BOSEPO team with a project “Hydrogen Fuel Cell Car”, and at the I-SWEEEP 2012 was also a gold medal winner, the BOSEPO team with project on environmental issue ‘Algae: Eco-friendly Power Plants of Future’.

BOSEPO finalists presenting BiH students’ project ideas successfully participated at the 19th and 20th International Environmental Project Olympiad (INEPO) held in Turkey by participation of 50 countries all over the world.
Four BiH teams won at the INEPO 2012 the silver medals for the projects: “Making pure water and electricity from wasted material”; “Are there dangerous level of lead in local soil?” ; “Graft Hybrids- Reducers of carbon dioxide concentration in the air” and “Using Macro invertebrates as Bioindicators in Ecological Assessment of Fresh Waters’ Quality”.

The BOSEPO finalists also attended at the International Young Inventors Project Olympiad (IYIPO) held in Tbilisi, Georgia and at the International Euroasia Environmental Project Olympiad (IEPO Euroasia) held in Baku, Azerbaijan, and brought three gold medals: one in 2011 and two in 2012.

Conclusions

Through a project preparation in particular domain of science, and particularly through PBL, BOSEPO participants develop a deeper understanding of scientific content of project for learning science deeper and wider than they learn in the official science curriculum. They have remarkably number of opportunities, challenges and different domains of inquiry to promote PBL.

Our findings according to the first research question show that BOSEPO fairs and competitions bring the opportunities for implementation of PBL as a method of teaching and learning science more effectively by both students and science teachers. These successful BOSEPO manifestations also showed numerous benefits for high school students to be better prepared for their future undergraduate (university) education. They faced with independent work and a skill using many printed and online resources for learning by inquiry what is a trendy method of teaching/learning science. Created BOSEPO projects open several possibilities for high school student to have a personal work that one wants to do well and with an educational purpose. Science teachers have very important roles advising and guiding students and they activate students’ needs to know content of projects, and they initiate them to use different sources for learning and preparing all required elements for establishing a project from its ideas all in the scientific manner of learning and doing.

Collaboration was essential to the BOSEPO projects. Students formed by teams (mostly in pairs) and started to think about what duties they would do and how they would realize their ideas for working together on a project. Their teachers helped them how to use time, learning sources, task organizers, and different materials or technology to create project elements. In writing own journals they practiced oral presentation or poster skills learned to produce project for exhibition, but in the same time students reflected their thinking, brainstorming, problem-solving processes and scientific arguing for giving explanations when they were faced with jury members during their project assessments. They synthesized the information gathered and used it to prepare both project application and team’s product related to the treated energy, environment, and engineering questions or issues they covered.

In BOSEPO fair and competition the student teams presented their project products addressing them at the BOSEPO exhibitions in front of jury members, but of peers, representatives of community, government organizations, and their teachers. Students presented their project works to audience by crossing the bridges of originality, quality and a dose of professionalism in an innovative and creative work that people outside of their classroom might see or use. On the other hand BOSEPO participants could discover some of challenges that a real work of a scientist can bring. The BOSEPO participants learned the important
elements in the scientific process of PBL by the posters created or presentations on laptops, a device for using different energy sources, or other kind of products. They were engaged in a process of inquiry, critique, revision and assessment of the project products.

According to the both authors’ findings (Z.H. as a jury member, and M.K.C. as students’ advisor) BOSEPO participants showed many carefully prepared projects that took nearly three-months work for the best among them. The most important outcome of the BOSEPO competitions is a larger number of students who have experienced the scientific pathway, studying collaboratively from variety of scientific references (the textbooks, scientific books, scientific journals, project reports, etc.). On the other hand, students with a clear educational purpose have been directed towards science and scientific research, innovative activities, creative thinking and practical application of integrated knowledge from different fields of science education fields and interests.

All who received gold medals at the international project competitions are subjects of a great honor with significant achievement for all subjects involved in the international missions abroad as BiH high school students. Most topics of the awarded projects are related to the environmental issues presenting the sensitivity of students to the environmental and ecological problems. They are investigating the solutions of these problems as a common idea of the humanity.

We believe and expect optimistically that BOSEPO should expand its activities among high school students throughout the country and in the region. This is a particular importance for cultural level of science education to meet and exchange students’ ideas from various regions of BiH. BOSEPO initiatives could bring young people closer and let them use their ideas to develop BiH society.

Acknowledgements

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References

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Impact of IBSE Methods and IBSE Materials on Student/Teacher Learning

Z. Ješková, University of P.J, Šafárik, Košice, Slovakia
M. Kireš, University of P.J, Šafárik, Košice, Slovakia
C. Fazio, University of Palermo, Italy
E. McLoughlin, Dublin City University, Ireland
E. Kedzierska, CMA, Amsterdam, The Netherlands
V. Žák, Charles University, Prague, Czech Republic
M. Kekule, Charles University, Prague, Czech Republic

Abstract

This study reports on the use of Inquiry-based science education (IBSE) materials and activities on the concept of Sound that have been used to teach lower and upper secondary school students by teachers who have participated in IBSE teacher education (Slovakia, Italy) as well as to teach pre-service teachers (Ireland). An IBSE method has been adopted by the ESTABLISH project (FP7, 2010-2013) to promote the implementation of innovative teaching and learning approaches for student-led inquiry based activities in the classroom. An IBSE approach is considered to encourage students’ active involvement in their learning compared to traditional methods. This project has developed teaching and learning materials for teachers and students that facilitate inquiry-based learning. An inevitable presumption to the effective implementation of IBSE is a well-trained teacher who is confident and competent in the appropriate use of IBSE methods of teaching. Hence, in-service teachers have participated in at least 10-hours professional development training to experience and develop their inquiry based teaching strategies using specifically developed materials. However, for any change in teaching methodology and/or curricula to occur, evidence must be clearly shown of its value in teaching and its impact on student learning. Therefore, the participating teachers implementing IBSE within their classrooms are provided with instruments and tools to collect information from students as well as collect teachers’ feedback about the impact of IBSE on their students. Evidence of the impact of this approach and materials has been collected from both the participating teachers and their students and the results and feedback of this teaching approach and the impact of IBSE on the students will be presented. In particular, the impact on students’ appreciation of the importance of science and technology in society, the impact on students’ inclination towards taking up careers in science and the impact on intrinsic motivation for learning science will be discussed.

Introduction

Educational systems within Europe are currently facing a massive shift towards the implementation of Inquiry based science education (IBSE). An IBSE approach is considered to encourage students’ active involvement in their learning compared to traditional methods. However, it is not easy to implement this way of teaching into classes since the success of the education reform movement requires consonance of many elements to be taken into account, such like improvements in in-service and pre-service teacher training, change in curricula and student assessment, instructional materials available for easy use of teachers, positive atmosphere towards these trends at school, etc. (Roschelle et col., 2000). The European 7th framework project ESTABLISH (http://www.establish-fp7.eu) is focused at supporting the use of IBSE methods into classes across Europe. Within the project, teaching and learning materials have been developed to facilitate inquiry-based learning. In order to develop teachers confident in the use of IBSE, in-service teacher training was provided to enable teachers to experience and develop their inquiry based teaching strategies using appropriate teaching and learning materials. Pre-service teachers experienced this way of teaching as well in their own process of learning science. The in-service teachers that participated in IBSE workshops have implemented the IBSE materials provided in their classroom. They were also provided with instruments in order to collect information and data about the impact of IBSE on their students. The evaluation of the impact of these IBSE materials and approaches for teaching Physics concepts was carried out and analysed for three different countries, namely Italy, Ireland and Slovakia.
**Methods**

In the discipline of physics the project partners are developing several units, i.e. Sound, Heating and Cooling: Designing a Low Energy House, Direct current electricity, Light: Display and Imaging Technologies, Medical Imaging. All the developed IBSE units have the same structure that involves, providing details of:

1. Teacher information (Unit description, IBSE character, Science content knowledge, Pedagogical content knowledge, Industrial content knowledge, Learning paths, Assessment, Student Learning Activities

2. Classroom materials involving students’ worksheets and other materials needed within the lesson.

Accordingly, the unit of Sound has been the first unit to be implemented and tested in the school classroom. First, in-service and pre-service teachers participated at teacher training workshops according to agreed structure considering the national curriculum and other national specifics, e.g. participants’ current experience in the field of IBSE.

Pre-service teachers were involved in introductory lectures to IBSE and 9-hours of inquiry-based labs (Ireland) with emphasis on inquiry-questioning skills. After these sessions their attitude towards IBSE was probed as well as their assessment of their conceptual understanding of Sound concepts.

In-service teachers participated in at least 10-hours teacher-training (Slovakia, Italy) to enable them to implement this way of teaching in their own classrooms. Teachers who participated in teacher training on Sound by inquiry implemented selected activities in their own classrooms at secondary level in order to gain experience (Italy, Slovakia) in this approach. After implementing this way of teaching their attitudes towards IBSE was analysed (Italy). In order to gain feedback from students they were provided tools to collect evidence about the impact on students (Slovakia), in particular on students’ appreciation of the importance of science and technology in society, the impact on students’ inclination towards taking up careers in science and the impact on intrinsic motivation for learning science.

**Results**

**Implementation of IBSE in Slovakia**

Since 2008 when educational reform was implemented into the educational system, the Slovak national curriculum gives significant attention to scientific inquiry with emphasis on students’ active independent learning. However, Slovak teachers are not educated in this approach and there is a lack of instructional materials for teachers to use in the classroom.

In the period November 2011 to February 2012, 50 secondary schools science teachers participated in 4-days teacher training in IBSE. Following on from this, 14 physics teachers implemented activities from the Sound unit into their teaching, with each teacher implementing at least 3 activities in the period of February 2012 to June 2012. A total of 202 upper secondary schools pupils completed questionnaires before and after a series of activities, while 1302 upper secondary school pupils answered questionnaires after each lesson (for detailed information about the questionnaires see Kekule, M., Žák, V., 2012).

The questionnaire responses show that:

In the field of Interest/Enjoyment - to what extent students like the performed activity and find it interesting – students express the provided learning activities were interesting for them and they enjoyed them (fig.1).
Figure 1. Results for the question items – to what extent students like the performed activity and find it interesting (each question max. 7 points, item 12 has reversed score)

In the field of perceived choice – to what extent students perceive their choice when performing a given activity – students chose the middle option on average. Data indicates that the students lack of strong opinion about perceived choice (fig.2).

Figure 2. Results for the question items – to what extent students perceive their choice when performing a given activity (each question max. 7 points)

In the field of Value/Usefulness – how students perceive the value/usefulness of a given activity for themselves – students overall agreed with each item. The results are similar to the result of Interest/Enjoyment dimension. Students express the provided activities were slightly useful for them (fig.3).
Another set of question items was aimed at determining the level of communication during the activity (table 1). Students considered how often they communicated using a five-point scale (1-almost never, 2-seldom, 3-sometimes, 4-often and 5-almost always). The communication levels described in items 1 and 2 were perceived to happen more often indicating that students think that they talked to each other about solving problems, however, considering explaining ideas to each other, students chose the middle option on average.

Table 1. Questionnaire items on students’ communication during the activity (adapted from CLES questionnaire (Taylor, P. C., Fraser B. J., & White, L. R., 1994))

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>St dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>I get the chance to talk to the other students.</td>
<td>3,83</td>
<td>1,06</td>
</tr>
<tr>
<td>I talk with other students about how to solve problems</td>
<td>3,49</td>
<td>1,05</td>
</tr>
<tr>
<td>I explain my ideas to other students</td>
<td>3,08</td>
<td>1,08</td>
</tr>
<tr>
<td>I ask other students to explain their ideas</td>
<td>2,98</td>
<td>1,08</td>
</tr>
<tr>
<td>Other students ask me to explain my ideas</td>
<td>2,80</td>
<td>1,09</td>
</tr>
<tr>
<td>Other students explain their ideas to me.</td>
<td>3,06</td>
<td>1,05</td>
</tr>
</tbody>
</table>

In the before and after whole teaching (series of activities) questionnaire several aspects were examined. The results were compared using appropriate statistical testing. A set of 16 questions were used to assess how students perceive the role of science and technology in society (table 2). Students used a four-point scale to express the extent to which they agree or disagree with the statement. The responses to these set of questions indicates that there is no statistical difference between pre and post IBSE experience responses.
Table 2. Examples of questionnaire items assessing students’ perception of the role of science and technology in society (scaled 1…4, disagree…agree) *(adapted from ROSE questionnaire (Schreiner, C., Sjøberg, S., 2004))*

<table>
<thead>
<tr>
<th>Item</th>
<th>mean</th>
<th>St dev</th>
<th>mean</th>
<th>St dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science and technology are important for society</td>
<td>3,73</td>
<td>0,61</td>
<td>3,48</td>
<td>0,76</td>
</tr>
<tr>
<td>New technologies will make work more interesting</td>
<td>3,02</td>
<td>0,79</td>
<td>3,00</td>
<td>0,95</td>
</tr>
<tr>
<td>Science and technology can solve nearly all problems</td>
<td>2,05</td>
<td>0,83</td>
<td>2,11</td>
<td>0,94</td>
</tr>
<tr>
<td>We should always trust what scientists have to say</td>
<td>2,02</td>
<td>0,81</td>
<td>2,16</td>
<td>0,87</td>
</tr>
<tr>
<td>Scientists are neutral and objective.</td>
<td>2,29</td>
<td>0,86</td>
<td>2,41</td>
<td>0,88</td>
</tr>
<tr>
<td>Scientific theories develop and change all the time</td>
<td>3,32</td>
<td>0,77</td>
<td>3,16</td>
<td>0,85</td>
</tr>
</tbody>
</table>

In the set of questions assessing student opinion about learning and understanding science (table 3), the analysis shows significant difference between responses to the pre and post questionnaires in items 2 and 6.

Table 3. Examples of test items results on opinion about learning and understanding science (scaled 1…4, disagree…agree) *(adapted from EBAPS questionnaire (Louca, L., Elby, A., Hammer, D., & Kagey, T., 2004))*

<table>
<thead>
<tr>
<th>Item</th>
<th>mean</th>
<th>St dev</th>
<th>mean</th>
<th>St dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. When it comes to understanding physics or chemistry, remembering facts isn’t very important.</td>
<td>1,70</td>
<td>1,28</td>
<td>2,27</td>
<td>1,23</td>
</tr>
<tr>
<td>5. When learning science, people can understand the material better if they relate it to their own ideas.</td>
<td>2,77</td>
<td>1,33</td>
<td>2,33</td>
<td>1,38</td>
</tr>
<tr>
<td>6. If biology, physics or chemistry teachers gave really clear lectures, with plenty of real-life examples and practice problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.</td>
<td>0,52</td>
<td>0,83</td>
<td>0,88</td>
<td>1,09</td>
</tr>
<tr>
<td>7. To understand chemistry and physics, the formulas (equations) are really the main thing. The other material is mostly to help you decide which equations to use in which situations.</td>
<td>1,87</td>
<td>1,28</td>
<td>1,86</td>
<td>1,25</td>
</tr>
</tbody>
</table>

There was a set of questions assessing students’ opinion about science lessons and their attitude towards taking up career in science or technology (table 4). The analysis of this field shows significant difference between pre and post questionnaire in the items 1, 9, 11 and 15. Their positive attitude towards science lessons increased (item 15) however there is no significant difference in up–take of careers in science or technology after experiencing IBSE activities.

Table 4. Examples of test items results on opinion about how students perceive science lessons and their attitude towards taking up career in science or technology (scaled 1…4, disagree…agree) *(adapted from ROSE questionnaire (Schreiner, C., Sjøberg, S., 2004))*

<table>
<thead>
<tr>
<th>Item</th>
<th>mean</th>
<th>St dev</th>
<th>mean</th>
<th>St dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. School science is a difficult subject.</td>
<td>2,77</td>
<td>0,89</td>
<td>2,93</td>
<td>0,84</td>
</tr>
<tr>
<td>3. School science is rather easy for me to learn.</td>
<td>2,38</td>
<td>0,78</td>
<td>2,23</td>
<td>0,83</td>
</tr>
<tr>
<td>9. School science has made me more critical and skeptical.</td>
<td>2,05</td>
<td>0,93</td>
<td>2,38</td>
<td>0,85</td>
</tr>
<tr>
<td>11. School science has increased my appreciation of nature.</td>
<td>2,36</td>
<td>0,96</td>
<td>2,57</td>
<td>0,97</td>
</tr>
<tr>
<td>14. I would like to become a scientist.</td>
<td>1,93</td>
<td>1,03</td>
<td>2,02</td>
<td>1,00</td>
</tr>
<tr>
<td>15. I would like to have as much science as possible at school.</td>
<td>2,00</td>
<td>0,93</td>
<td>2,16</td>
<td>1,02</td>
</tr>
<tr>
<td>16. I would like to get a job in technology.</td>
<td>2,09</td>
<td>1,05</td>
<td>2,26</td>
<td>1,01</td>
</tr>
</tbody>
</table>
Based on the responses to these questionnaires it can be clearly seen that the students’ opinion on the activities they carried out is positive; they consider them interesting, enjoyable and useful. There is indication of a slight impact on students motivation and attitude towards science lessons, nevertheless the impact on students views on science and its role in society has not changed, neither has their inclination towards taking up careers in science or technology.

**Implementation of IBSE in Italy**

Some relevant aspects of IBSE are formally present in the Italian National Science Curriculum. It is clearly stated that at the end of their studies the students should be confident with the different aspects of the experimental methods, where the experiment is to be considered a reasoned inquiry of natural phenomena, a tool for control of different interpretative hypotheses and critical analysis of data and reliability of measurement procedures. However, Italian science teachers are often not well trained in IBSE and its relevant aspects. This applies particularly to upper secondary school physics teachers that often have a mathematics degree and very limited experience in laboratory activities from their university studies.

Within the ESTABLISH project, a one-day presentation of IBSE was held in Palermo in April 2010 for in-service teachers from all over Sicily. After this event, teachers were selected and 30 teachers initially agreed to participate but actually a total of 22 participated in all the subsequent activities (12 upper secondary school teachers and 10 lower secondary school teachers).

Five “official” full days of training to the IBSE methodologies were organized, between April 2010 and November 2011 at an IBSE laboratory in the Physics Department at the University of Palermo. But many more afternoons of informal training were also facilitated for teachers wishing to practice more with the IBSE material and documentation made available on the ESTABLISH website, and with the technology based equipment available in the laboratory. This equipment is similar to that often present in the teachers’ own school laboratories, but sadly hardly used due to lack of training/time/motivation.

After this training phase, the teachers used some parts of two of the ESTABLISH Units in their classrooms throughout 2012: “Sound” and “Heating and Cooling: Designing a Low Energy House”. Two of the teachers subsequently incorporated the Sound Unit in their own teaching, adapting their lesson and topics taught in their classes to the relevant content and methods. Three half-day meetings were held at the end of March 2012 to review what had been done with the students and to make some needed changes and amendments to the various pedagogical activities. A further three half-day meetings were held in May 2012 and were dedicated to reviewing the final outcomes from the Unit trials and to collect teacher feedback about the actual implementation of IBSE activities in their schools.

In general, it was agreed that the IBSE activities were well fitted to the Italian Physics curriculum. It was proposed that the Units’ structure needed some adaptation and, more specifically, teachers requested that more detail should be given in describing the activities to be performed and in the theoretical aspects behind the IBSE activities. Something all teachers noticed and reported was the unconditional and substantial enthusiasm of students participating in IBSE activities. The believed that the students always found that physics introduced through an IBSE methodology was more enjoyable and less difficult to follow and understand.

Before starting the training phase at Department of Physics teachers answered a pre-questionnaire aimed at analyzing their views of inquiry teaching and approaches, as well as their attitudes and views towards science and teaching science. After completing the training sessions and experimenting the IBSE methodology in their classes teachers were answered a post-questionnaire to see if the IBSE training and in-class implementation was effective in modifying some aspects of their views of inquiry teaching and approaches. The comparison between teacher answers before and after IBSE activities are reported in Tables 5, 6 and 7.

From Table 5 it is easy to see that after training and in-class implementation of IBSE methods and teaching units teachers seem to better understand the meaning of inquiry based education, their role as teachers in an IBSE teaching environment and the possibility to effectively perform IBSE in their classrooms. Also, after training, more teachers believe that the use of inquiry is appropriate to achieving the aims of the curriculum.
Table 5. Examples of test item results on teachers’ views of Inquiry (scaled 1 … 5, disagree … agree)

<table>
<thead>
<tr>
<th>before mean</th>
<th>before St dev</th>
<th>after mean</th>
<th>after St dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>I don’t fully understand inquiry based science education.</td>
<td>2.72</td>
<td>0.88</td>
<td>1.59</td>
</tr>
<tr>
<td>I don’t fully understand my role as a teacher in an inquiry classroom.</td>
<td>2.27</td>
<td>0.63</td>
<td>1.50</td>
</tr>
<tr>
<td>I don’t fully understand the role of the students in an inquiry classroom.</td>
<td>2.09</td>
<td>0.29</td>
<td>1.13</td>
</tr>
<tr>
<td>I think inquiry takes too much classroom time for me to implement</td>
<td>2.82</td>
<td>0.58</td>
<td>1.82</td>
</tr>
<tr>
<td>The use of inquiry is appropriate to achieving the aims of the curriculum.</td>
<td>4.00</td>
<td>0</td>
<td>4.5</td>
</tr>
<tr>
<td>Inquiry-based teaching is only suitable for very capable students</td>
<td>2.09</td>
<td>0.29</td>
<td>1.63</td>
</tr>
<tr>
<td>Inquiry will never be my main teaching method.</td>
<td>2.27</td>
<td>0.88</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Fortunately, the need for links between Industry Content Knowledge and what it is taught at school was clear to the teacher sample also before the IBSE training, as shown in Table 6. Nevertheless an improvement on teachers’ views about this aspect can also be considered as a result of the IBSE activities implementation.

Table 6. Examples of test item results on teachers’ views on Industrial Content Knowledge and Authentic Experiences (scaled 1 … 5, disagree … agree)

<table>
<thead>
<tr>
<th>before mean</th>
<th>before St dev</th>
<th>after mean</th>
<th>after St dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>I want my students to know about the latest developments and applications of science and engineering.</td>
<td>4.18</td>
<td>0.39</td>
<td>4.41</td>
</tr>
<tr>
<td>I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom.</td>
<td>3.68</td>
<td>0.48</td>
<td>4.32</td>
</tr>
<tr>
<td>I often show students the relevance of science in industry</td>
<td>4.72</td>
<td>0.45</td>
<td>4.36</td>
</tr>
<tr>
<td>My students understand the importance of science and technology for our society.</td>
<td>4.09</td>
<td>0.75</td>
<td>4.00</td>
</tr>
<tr>
<td>If I had more information about industrial processes, I would use it in my teaching.</td>
<td>4.18</td>
<td>0.39</td>
<td>4.23</td>
</tr>
</tbody>
</table>

Table 7 shows that the IBSE training seems to have modified the teachers’ inclination at managing classrooms where each student group is doing different activities, something not common in Italian science lessons, where a traditional, lecture-based approach is the most common one. Strangely, some confusion can be deduced from the increase in teacher sense of inadequacy when they don’t know the answers to specific questions and when they are to pose questions they are unsure of the answer themselves. Maybe a longer training with IBSE methods was needed to give teacher more confidence with the typical aspects of scientific inquiry.
Table 7. Examples of test item results on teachers’ views on teaching Science (scaled 1 ... 5, disagree ... agree)

<table>
<thead>
<tr>
<th></th>
<th>before</th>
<th></th>
<th>after</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>St dev</td>
<td>mean</td>
<td>St dev</td>
</tr>
<tr>
<td>If a student investigation leads to an unexpected result I should always tell the student the right answer/result.</td>
<td>3.95</td>
<td>0.48</td>
<td>1.77</td>
<td>0.75</td>
</tr>
<tr>
<td>I find it difficult to manage a classroom where each student group is doing different activities.</td>
<td>4.45</td>
<td>0.67</td>
<td>1.86</td>
<td>0.64</td>
</tr>
<tr>
<td>I am unsure how to ask students higher order questions that promotes thinking.</td>
<td>1.86</td>
<td>0.64</td>
<td>2.36</td>
<td>0.95</td>
</tr>
<tr>
<td>I have sufficient knowledge of science to implement an inquiry lesson effectively</td>
<td>3.54</td>
<td>0.59</td>
<td>3.18</td>
<td>0.79</td>
</tr>
<tr>
<td>I am uncomfortable teaching areas of science I have limited knowledge of.</td>
<td>3.86</td>
<td>0.64</td>
<td>3.45</td>
<td>0.75</td>
</tr>
<tr>
<td>If I don’t know the answers to students questions I feel inadequate as a teacher</td>
<td>1.41</td>
<td>0.91</td>
<td>3.00</td>
<td>0.75</td>
</tr>
<tr>
<td>I am uncomfortable with asking questions, in my class, where I am unsure of the answer myself.</td>
<td>1.5</td>
<td>0.80</td>
<td>3.54</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Implementation of IBSE in Ireland

The national curriculum in Ireland for lower secondary science emphasizes teaching strategies that encourage investigative work as well as experimental prescribed work. The syllabus promotes the development of logical thinking and reasoning, and skills of observation, measurement, interpretation, numeracy, problem solving and decision making. With respect to the IBSE elements there are opportunities for students to investigate their own problem by searching for information and planning investigations. Mostly students take problems assigned by the national State Examination Commission. The students’ investigation plans are assessed using a summative exam/review at the end of the lower secondary level (Junior Cycle) ~15 years. However, depending on teachers’ capabilities to manage inquiry and such open teaching, they may wish to set the investigation so as to limit the openness of the problem, and may present the required information and experiments for the students, again limiting their opportunity to search for information, and plan their investigation. So while the national curriculum includes IBSE elements, in general, teachers are not educated at either pre-service or in-service level and there is a lack of appropriate instructional materials available to support the teaching of national syllabi.

In the period February 2012 to May 2012, 37 pre-service physics teachers participated in introductory lectures plus 9 hours of hands-on Inquiry Based Labs using materials from the Sound Unit. 39% of these students considered themselves beginners while 61% of them expressed that they had some experience with inquiry-based teaching. The Inquiry Based Labs were focusing on developing inquiry questioning skills. Before the labs sessions started, students answered a pre-questionnaire (table 5) on their views of inquiry. After completing the sessions they answered a concept based assessment (table 6) as well as a post-questionnaire (table 10) on their views of inquiry teaching and approaches.

As regards responses to questions, these pre-service teachers were positive about the values and benefits of inquiry as a methodology. Importantly, 67% believed the use of inquiry is appropriate to achieving the aims of the curriculum and 70% expressed confidence in their understanding of inquiry based science education.

However, pre-service teachers appeared unconfident and uncomfortable with delving outside the limits of their own knowledge in the classroom. 61% of teachers felt uncomfortable with teaching areas of science they had limited knowledge of and 64% admitted to being uncomfortable with asking questions where they are unsure of the answer themselves.

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They were very divided in their responses as to their role as the teacher in the classroom and 54% disagreed with the statement “my goal is to transfer factual knowledge to the students” while 55% felt that teaching was more effective when all students are doing the same activity at the same time”. These conflicts arise from their lack of experience in the classroom and their understanding of the state examinations in science.

**Table 8. Pre-service teachers pre-questionnaire responses**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>I don’t fully understand inquiry based science education.</td>
<td>70% disagreed</td>
</tr>
<tr>
<td>Inquiry will never be my main teaching method.</td>
<td>28% uncertain or agreed</td>
</tr>
<tr>
<td>I don’t fully understand the role of the students in an inquiry classroom.</td>
<td>22% uncertain or agreed</td>
</tr>
<tr>
<td>The use of inquiry is appropriate to achieving the aims of the curriculum.</td>
<td>67% agreed</td>
</tr>
<tr>
<td>Scientific theories (e.g. atomic theory) are constant unchanging bodies of knowledge.</td>
<td>27% agreed</td>
</tr>
<tr>
<td>Scientific knowledge is primarily focused on knowing facts.</td>
<td>27% agreed</td>
</tr>
<tr>
<td>Developing students’ specific content knowledge is much more important than developing their thinking and reasoning processes.</td>
<td>78% disagreed</td>
</tr>
<tr>
<td>Good teachers encourage student discussion on scientific topics relevant to everyday life.</td>
<td>95% agreed</td>
</tr>
<tr>
<td>I can easily relate scientific concepts in the curriculum to phenomena beyond the classroom.</td>
<td>89% agreed</td>
</tr>
<tr>
<td>Teaching is more effective when all students are doing the same activity at the same time.</td>
<td>55% agreed</td>
</tr>
<tr>
<td>My goal is to transfer factual knowledge to the students.</td>
<td>54% disagreed</td>
</tr>
<tr>
<td>If a student investigation leads to an unexpected result I should always tell the student the right answer/result.</td>
<td>16% agreed</td>
</tr>
<tr>
<td>I am uncomfortable teaching areas of science I have limited knowledge of.</td>
<td>61% agreed</td>
</tr>
<tr>
<td>I would be uncomfortable with asking questions, in my class, where I am unsure of the answer myself.</td>
<td>64% agreed</td>
</tr>
</tbody>
</table>

As the focus of these inquiry labs was to develop the student understanding of physics concepts relating to the topic of Sound through IBSE, the students were required to answer a series of questions relating to various concepts. In all questions they were asked to give and explain the answer provided. As can be seen in (table 9), understanding of concepts such as describing the production and propagation sound were well expressed but more difficult concepts such as explaining the wave nature of sound and sound as a form of energy still challenged these students and only basic understanding was evidenced.

**Table 9. Post-assessment of Sound Concepts**

<table>
<thead>
<tr>
<th>Concept</th>
<th>Some ideas</th>
<th>Good understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe a sound wave</td>
<td>27%</td>
<td>40%</td>
</tr>
<tr>
<td>Propagation of the human voice</td>
<td>35%</td>
<td>65%</td>
</tr>
<tr>
<td>How humans produce sound</td>
<td>24%</td>
<td>73%</td>
</tr>
<tr>
<td>Speed of Sound</td>
<td>24%</td>
<td>76%</td>
</tr>
<tr>
<td>Pressure variation versus time graphs</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>Sound as wave motion</td>
<td>92%</td>
<td>8%</td>
</tr>
<tr>
<td>Sound as a form of energy</td>
<td>84%</td>
<td>14%</td>
</tr>
<tr>
<td>Posing inquiry questions on resonance</td>
<td>46%</td>
<td>46%</td>
</tr>
</tbody>
</table>

A set of open questions were presented to the students to obtain feedback on their understanding of IBSE (table 10) after completing these sessions. 87% expressed that they felt they now understood inquiry.
better and commented on the benefits of inquiry teaching. 97% of them identified the role of the teacher to guide/ask questions in the inquiry classroom where the students are active and self-directed. When asked what was the most important inquiry skill that they gained from these labs, the students recognized that they had developed questioning skills (48%), experience in planning and doing investigations (27%) and learning from mistakes (22%). 77% of the students were very positive about the materials from the ESTABLISH units and felt they gave them good ideas and developed understanding and skills.

### Table 10. Feedback on Inquiry Process

<table>
<thead>
<tr>
<th>Question</th>
<th>Student responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have your opinions of inquiry based teaching changed?</td>
<td>87% - understand inquiry better and see benefits</td>
</tr>
<tr>
<td></td>
<td>13% - already thought it was good/best</td>
</tr>
<tr>
<td>Did you enjoy using the ESTABLISH inquiry materials?</td>
<td>77% - positive - good ideas, developed understanding,</td>
</tr>
<tr>
<td></td>
<td>skills and doing investigations</td>
</tr>
<tr>
<td>Do you understand better how to implement an inquiry based classroom?</td>
<td>13% - felt not good ideas or enough time</td>
</tr>
<tr>
<td>Are you now more willing to use inquiry methodologies in your future</td>
<td>97% identify role of teacher is to guide/ask questions</td>
</tr>
<tr>
<td>classroom?</td>
<td>and students are active &amp; self-directed</td>
</tr>
<tr>
<td></td>
<td>89% - positive- more effective/engaging, developed</td>
</tr>
<tr>
<td></td>
<td>better understanding/knowledge.</td>
</tr>
<tr>
<td></td>
<td>Concerns on time constraints, need for background</td>
</tr>
<tr>
<td></td>
<td>theory and other approaches.</td>
</tr>
<tr>
<td></td>
<td>65% - more useful</td>
</tr>
<tr>
<td>Do you think inquiry is more or less useful than other approaches to</td>
<td>22% - equally as useful</td>
</tr>
<tr>
<td>teaching?</td>
<td>13% - depends on students/topic</td>
</tr>
<tr>
<td>Do you think you have learned more about sound using the inquiry approach</td>
<td>60% - more learnt/understood by doing</td>
</tr>
<tr>
<td>(versus traditional approaches)?</td>
<td>19% - same amount</td>
</tr>
<tr>
<td></td>
<td>14% - learn more from traditional approaches (but</td>
</tr>
<tr>
<td></td>
<td>3% understand more from inquiry)</td>
</tr>
<tr>
<td>In school, were you taught using inquiry approaches?</td>
<td>76% - no experience</td>
</tr>
<tr>
<td>How do you believe you learn best?</td>
<td>24% - some in different topics/levels</td>
</tr>
<tr>
<td></td>
<td>72% - Inquiry approaches</td>
</tr>
<tr>
<td></td>
<td>14% - Traditional approaches</td>
</tr>
<tr>
<td></td>
<td>14% - Mixture of the two</td>
</tr>
<tr>
<td>In what areas would you most like to improve as a teacher?</td>
<td>19% - classroom management</td>
</tr>
<tr>
<td></td>
<td>19% - using inquiry</td>
</tr>
<tr>
<td></td>
<td>22% - teaching methods &amp; differentiation</td>
</tr>
<tr>
<td>What was the most important inquiry skill you gained from these labs?</td>
<td>48% - questioning skills</td>
</tr>
<tr>
<td></td>
<td>27% - planning and doing investigations</td>
</tr>
<tr>
<td></td>
<td>22% - learning from mistakes</td>
</tr>
</tbody>
</table>

Overall, the pre-service teachers really enjoyed the experience of Inquiry based labs and felt they had gained deeper insight into the inquiry methodology and the role of the teacher/student in the inquiry classroom. They believed it was an effective method to develop conceptual understanding and subject knowledge in science. However, their conceptual knowledge increased only in some Sound topics and deeper conceptual understanding was not achieved by all or on all topics.
Conclusions and implications

The IBSE teaching and learning materials developed within the ESTABLISH project have been successfully implemented within secondary schools physics lessons (Slovakia, Italy) and in pre-service physics teachers education (Ireland). In-service teachers participated in training workshops in order to increase their familiarity with IBSE strategies before they implemented selected activities in their own classrooms while pre-service teachers were in the role of students carrying out the activities themselves. The experiences of the teachers have been collected and reported as well as responses to questionnaires answered by students carrying out IBSE activities on the topic of Sound.

The results of discussions and questionnaires answered by second level students clearly shows their positive attitude to IBSE, they consider the activities interesting, enjoyable and useful and they even expressed a slight positive shift in attitudes towards science lessons. In their communication of science they express they have a chance and talk with other students about how to solve problems that is a good signal since the activities strongly support peer discussion as one of the important aspects of IBSE. However, there were also many items without any significant changes even after engaging in a series of IBSE activities, e.g. the impact on students view on science and its role in society has not changed, neither has their inclination towards taking up careers in science or technology.

In service teachers found inquiry teaching a rewarding teaching experience. However even after participating in training workshops, teachers still lack the necessary skills for consistent application of IBSE methods in the classroom. They will need ongoing professional development to support their increased use of it in the classroom. The pre-service science teachers also expressed positive attitudes and improved appreciation of IBSE following their experiences. They expressed that they had developed inquiry skills, such as questioning, planning and doing investigations and learning from mistakes. However, they also recognised that that required further professional development in classroom management and using inquiry and other such teaching methods. It is clear that for all teachers, that both initial and continual teacher education needs to be facilitated to support the use of inquiry and impact of IBSE in the teaching and learning of science.

Within the ESTABLISH project, several IBSE units in physics have been developed and so much more curriculum and translated materials and teacher training will be provided through the project, with online teacher training as a core aspect of this. This should certainly offer teachers on-going support beyond the face to face meetings.

Acknowledgement

This work is the result of the international 7FP project ESTABLISH (European Union’s Seventh Framework Programme FP7/2007-2013 under grant agreement n° 244749).

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ESTABLISH project, available on <http://www.establish-fp7.eu>


Slovak national curriculum in physics for secondary schools, available on <www.statpedu.sk>

Irish national curriculum in science for secondary schools, available on <www.ncca.ie/en/>


Proceedings of The World Conference on Physics Education 2012


How IBSL (Inquiry Based Science Learning) is the IBSL Approach?

Tom Lambert, PONTOn vzw, (Promotion and Support of Natural Sciences and Technology for Education), Sint-Jozefsinstituut Borsbeek, Belgium, tomlambert.82@gmail.com

Abstract

The recent curriculum changes in Flanders moved the educational approach from science learning towards inquiry based science learning (IBSL). This was integrated in the newly written textbooks, but a lot of teachers experience a gap between the textbook and the desired ISBL effect. In this article, the Laboratory Structure and Task Analysis Inventory (LAI) is used to check how IBSL the IBSL approach really is, which confirms the teachers’ experience. Also, the powerfulness of the LAI for creating (more) IBSL teaching activities shall be illustrated.

Introduction

The recent curriculum changes in Flanders moved the educational approach from science learning towards enquiry based science learning. With the introduction of the curriculum for the new course “natural sciences” [1] (which was introduced September 1st, 2010) and the adapted curriculum for the existing course “scientific initiation” [2] (of which the last version was introduced September 1st, 2010) for 12 – 14 year old students, the learning strategy for IBSL is covering the full secondary education now (12 – 18 year old students).

Of all the students in the second year of their secondary education (12 – 14 year old students), 70% chooses their majors in Latin, Greek-Latin and Modern Sciences. The other 30% chooses one of the other 12 majors. Of all the students in the second year of their secondary education, 50% chooses Modern Sciences as their major, resulting in the compulsory courses “social-economic initiation” (economy and humanities) and “scientific initiation”. [3] The main goal of both courses is student orientation towards their further secondary education: economy, humanities, sciences, Latin, Latin-Greek or sports.

The course “scientific initiation” is organized 2 or 3 50-minutes periods per week. The school can choose the number of periods per week.

The curriculum gives pedagogical freedom to the “scientific initiation” teacher, since it doesn’t include compulsory topics.
Table 1. Goals of the “scientific initiation” curriculum. [2]

Goals with regards to IBSL
- Recognize and name the parts of a scientific experiment.
- Observe and collect data from a scientific experiment.
- Perform an experiment in a scientific context.
- Display the collected data in tables and graphs.
- Recognize direct and inverse proportionality in graphs.
- Present the observations and collected data (oral / written).
- Create a hypothesis (based on an experiment) or create a model and perform a reality check.
- Interpret formulas and apply them in contexts.

Goals with regards to science and society
- See how the different sciences interact.
- See how science and society interact.

Attitudes
- Distinguish fact from opinion or conjecture.
- Formulate an opinion and bear in mind the opinion of others.
- Be willing to cooperate.
- Be willing to work with instructions.
- Be critical and objective.

Scientific goals
- Use and read the equipment correctly.
- Know the used physical quantities and their SI-units.
- Work safely and environmentally friendly.
- Use a model to describe and explain phenomena.
- Use a scientific correct language.

The curriculum also states that the lessons should be given with regards to both the “five E’s of science”- didactis (engage – explore – explain – elaborate – evaluate), as the IBSL approach.

A new series of textbooks has been written. Unfortunately the teachers experience a gap between the textbook and the desired ISBL effect.

Methods

The newly published textbooks are analyzed. In order to evaluate the IBSL approach, the Laboratory Structure and Task Analysis Inventory (LAI) [4] is used. The LAI was developed by Marlene Fuhrman in 1978 as a instrument to evaluate the research competence oriented approach for chemical practicums. It can, however, be used for IBSL approach evaluation of physics practicums or “scientific initiation” lessons. Basically, the LAI is a list of process skills for the student, which is divided in four categories. The deeper you go (the higher number you reach) in a category, results in a better achievement for the IBSL approach.
Table 2. The Laboratory Structure and Task Analysis Inventory (LAI).

<table>
<thead>
<tr>
<th>1.0 CONCEPTION, PLANNING AND DESIGN OF EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>The student:</td>
</tr>
<tr>
<td>1.1 Formulates question or problem to be investigated.</td>
</tr>
<tr>
<td>1.2 Formulates hypothesis.</td>
</tr>
<tr>
<td>1.3 Designs experiment (independent, dependent variables).</td>
</tr>
<tr>
<td>1.4 Designs observations and measurement procedures (including design of experiment and operational definitions).</td>
</tr>
<tr>
<td>1.5 Predicts results.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.0 EXECUTION OF EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>The student:</td>
</tr>
<tr>
<td>2.1 Observes, measures.</td>
</tr>
<tr>
<td>2.2 Manipulates.</td>
</tr>
<tr>
<td>2.3 Records results.</td>
</tr>
<tr>
<td>2.4 Calculates.</td>
</tr>
<tr>
<td>2.5 Explains or makes decisions about experimental techniques.</td>
</tr>
<tr>
<td>2.6 Works accordingly to own design.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.0 ANALYSIS AND INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>The student:</td>
</tr>
<tr>
<td>3.1 Transforms results into standard form (tables).</td>
</tr>
<tr>
<td>3.2 Determines relationships (could include graphs).</td>
</tr>
<tr>
<td>3.3 Discusses accuracy of data.</td>
</tr>
<tr>
<td>3.4 Discusses limitations / assumptions of experiment.</td>
</tr>
<tr>
<td>3.5 Formulates generalizations.</td>
</tr>
<tr>
<td>3.6 Explains relationships.</td>
</tr>
<tr>
<td>3.7 Formulates new questions / problems.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4.0 APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>The student:</td>
</tr>
<tr>
<td>4.1 Predicts based on results of investigation.</td>
</tr>
<tr>
<td>4.2 Formulates hypothesis for follow-up.</td>
</tr>
<tr>
<td>4.3 Applies experimental technique to new problem or variable.</td>
</tr>
</tbody>
</table>

Data and findings

The LAI is applied to two mutual topics that are covered in the newly written textbooks:

- A: mass and gravitational force
- B: mass, volume and mass density

Table 3. Results (LAI scores for the two mutual topics mentioned above).

<table>
<thead>
<tr>
<th>Publisher</th>
<th>WW what</th>
<th>WW</th>
<th>WW</th>
<th>WW</th>
<th>Project WW</th>
<th>Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<tr>
<td>B</td>
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<td>1.0</td>
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<td>4.0</td>
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</tbody>
</table>
Discussion and conclusion

Table 3 shows that some textbooks try to reach some goals of the IBSL approach. Categories 2 (execution of experiment) and 3 (analysis and interpretation) are covered the most. However, categories 1 (conception, planning and design of experiment) and 4 (applications) aren't covered at all by the textbooks.

It is important to keep in mind that table 3 is based on the textbooks only. The “real life” LAI scores can be different, with regards to the teaching strategies used by the actual teachers.

The results given in table 3 provide a proof of the teachers’ experience: there is a gap between the textbooks and the desired IBSL approach.

Apart from being a diagnostic instrument, the LAI can also be used as a tool for creating teaching strategies that reach higher LAI scores (and thus resulting in a more effective IBSL approach). All suggestions mentioned below are tried by the author in his classes.

Example with regards to topic A (covered in table 3):

All “scientific initiation” course books cover the topic of mass and gravitational force. After the introduction, the classic experiment is introduced: measure the mass of an object, attach the object to a dynamometer and write down the results in a table. Repeat this action several times and draw the graph, which leads to the well-known formula.

It’s a good experiment, however it doesn’t really enhance IBSL (since the students just follow the instructions).

Suggestion for improvement (A.1): Give the students a lot of tools and objects and let them design (in small groups) an experiment that looks for the link between mass and gravitational force. During this process, the teacher becomes a coach to discuss their ideas and to give indications for fine-tuning.

Suggestion for improvement (A.2): Give the students the formula. Give them also a lot of tools and objects and let them design (in small groups) an experiment that leads to the empiric proof of the formula. Again, the teacher becomes a coach to help and motivate the students.

Example with regards to topic B (covered in table 3):

The topic of mass, volume and mass density is covered in all “scientific initiation” course books. Generally, the topic ends with the study of buoyancy. Why end here? Why don’t we encourage our students to study buoyancy with a hands-on approach?

Suggestion for improvement (B): Let the students work together in small groups. Let them draw a construction plan of a boat, to be built with everyday materials. They will present their construction to the teachers and the class, and they can change their construction plan. Afterwards, they start building their boats. This leads to the evaluation: does the boat not sink, is the boat really built like the construction plan, how many concrete bricks can the boat carry before sinking,…

The LAI is also applied to suggestions for improvement A.1, A.2 and B:

Table 4. Results (LAI scores for the suggestions for improvement mentioned above).

<table>
<thead>
<tr>
<th></th>
<th>A.1</th>
<th></th>
<th>A.2</th>
<th></th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.4</td>
<td></td>
<td>2.4</td>
<td></td>
<td>1.5</td>
</tr>
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<td></td>
<td>3.3</td>
<td></td>
<td>2.6</td>
<td></td>
<td>2.6</td>
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<td></td>
<td>4.2</td>
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<td>3.5</td>
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<td>4.3</td>
</tr>
</tbody>
</table>
Conclusions
The LAI is a powerful tool for checking the IBSL value of experiments. The LAI is also a powerful tool for expanding classroom activities and creating teaching strategies which result in a more effective IBSL approach.

Acknowledgement
The author wishes to thank Ed van den Bergh for his interesting and motivating views on science education, as well as the other members of the General Assemble of PONTOn vzw for their inspiring views.

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[3]: http://ond.vvkso-ict.com/vvksosites/UPLOAD/2012/M-VVKSO-2012-008-B03.pdf
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Research Based Teaching Sequence on Electromagnetic Induction

Jenaro Guisasola and Kristina Zuza, Department of Applied Physics. UPV/EHU - University of the Basque Country, Spain

Abstract

Physics Education research indicates that there is a significant gap between the learning obtained by students and what teachers expect. Physics Education research has shown that the fundamental concepts of the electromagnetic induction theory are barely understood by students. This article proposes an interactive teaching sequence introducing the topic of electromagnetic induction. The sequence has been designed based on contributions from Physics Education research. Particular attention is paid to the relationship between experimental findings (macroscopic level) and theoretical interpretation (microscopic level). It will also present an example of the activities that have been designed, describing the implementation context and the corresponding findings.

Introduction

One of the greatest challenges in Physics Education revolves around helping students to build scientific models that they can use to understand natural phenomena. The challenge is particularly serious for scientific areas where progress is fast, phenomena are complex and a large quantity of prior information has built up. A representative example of one of these areas in physics is electromagnetic induction (EMI). During the 20th century great technological progress was made in the EMI field (electric motors, induction cookers, microphones, electric guitars, etc.). Consequently, the need arose to introduce the topic of EMI not only in the curriculum for introductory university physics courses but also in the secondary education curriculum.

From the educative point of view, the way the matter stands is not encouraging: comprehension of EMI theory involves concepts and laws that represent teaching and learning difficulties (Munley 2006, Guisasola et al 2011). From a practical point of view, lack of comprehension concerning the main characteristics of the EMI model gives students poor preparation to understand EMI’s technological benefits. From an academic point of view, EMI is a topic articulating different fundamental laws of electricity and magnetism; not understanding EMI means that students do not understand relationships between electric and magnetic fields. In short, not understanding EMI leads to not understanding the classic physics explanatory model of electromagnetic phenomena measured by Maxwell’s Laws (Lorrain et al. 2000). Dominant educative practice concerning EMI tends to focus its attention on memorising concepts and processes more than on a body of ideas and laws making up an explanatory model or understanding the relationships between the model’s different components (Chabay and Sherwood 2006). Significant and useful learning on EMI phenomena requires curriculum, instruction and evaluation all focussed on a set of ideas and procedures making up a scientific model of EMI.

This work describes the first part of a sequence for teaching electromagnetic induction in introductory university physics courses. In this study, we construct the sequence as part of the wide-ranging theoretical framework of developmental research. This theoretical framework inter-relates the design, development and application of a teaching sequence on a specific topic of the curriculum that normally lasts a few weeks in an evolving cyclical process, enlightened by the research findings (Lijssne 1995). As indicated by Meheut and Psillos (2004) “One distinguishing characteristic of a TLS is its inclusion in a gradual research-based evolutionary process aiming at interlacing the scientific and the student perspective.” We agree with Lijsen & Klaassen (2004) when they argue that designing teaching-learning sequences requires a complex process involving applying the general principles of didactics to specific teaching contexts for curriculum topics. They indicate that this task is not linear but a cyclical process with the aim of generating relevant knowledge on teaching and learning for its implementation in the classroom. Our study centres on understanding how we can help our students in the task of constructing an explanatory model for electromagnetic phenomena. In particular:

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1. How can we help students to understand the importance of electromagnetic induction for technological development of industrial apparatus and everyday life? How can we help students to understand the central role that electromagnetic induction theory plays in the relationship between electrical currents and magnetic fields?

2. How can we help students to understand when electromagnetic induction occurs and when it does not?

3. How can we help students to understand that the experimental measures obtained at a microscopic level are related to a primary explanatory model of electromagnetic induction that includes magnetic fields which vary over time and/or conductors moving in stationary magnetic fields?

**Designing the teaching-learning sequence**

We can start this section by describing the learning goals, and continue by describing the learning sequence that this research has produced. These goals are in line with the standard curriculum for a general physics course in the first years of university. We have been careful to limit the learning goals to a few lasting ideas as suggested by Tiberghien (2000), to focus instruction on these key ideas and highlight them to the students.

**Learning goals**

Learning Goal 1: understand the point of studying the topic and its applications. This goal focuses on students recognising EMI in their everyday life so they can see the importance of this phenomenon in their daily existence. Research into teaching sciences shows that the emotional and value-related aspects cannot be considered without making a close connection to cognitive processes when students are working on their activities in science classes (Zembylas, 2005).

Learning Goal 2: Become familiar with electromagnetic induction phenomena and build a first explanatory model. Once they have recognised the EMI phenomenon in their environment, the student must become familiar with this phenomenon. When does EMI occur? When does EMI not occur? We can propose activities for students to become familiar with this phenomenon whilst they start to construct the first explanatory model of EMI. These activities are designed to help students overcome any difficulties detected in the research. One of these difficulties lies in students identifying the magnetic field (and not its variation over time) as the agent generating EMI (Mauk & Hingley, 2005; Meng Thong & Gunstone, 2008; Guisasola et al. 2011). In addition to this widely documented difficulty, students have problems coming up with examples of EMI and they also use Faraday’s law without comprehension (Mauk & Hingley, 2005; Meng Thong & Gunstone, 2008; Venturini & Albe, 2002). In short, students are helped to investigate and analyse situations to be able to pass from an experimental model to an interpretive model of EMI.

Learning Goal 3: Use different explanatory models for Electromagnetic Induction with comprehension (field model and force model) and recognise how they complement each other and their differences. One the students have a first explanatory model of EMI (the magnetic flow variation is the EMI agent), we propose activities to formally define Faraday’s law and look at it in greater depth. We propose activities demonstrating that this is a valid law for explaining any of these phenomena at field level but activities are also proposed to tackle the same problems from a force model. We should take into account that the research has also found difficulties related to this learning goal. Applying Faraday’s law requires the concept of magnetic flux and several works conclude that flux is occasionally confused with field and this is a concept that is not understood (Venturini & Albe, 2002). As far as the force models and field models are concerned, Guisasola, Almudi and Zuza (2011) conclude that only a small proportion of students are capable of understanding and using both models.

To support the learning goals within the sequence, we can formulate a set of “driving problems” whose resolution implicates learning knowledge, reasoning and values included in the goals. Although we process each goal as a different entity associated with different teaching strategies, the different strategies are not implemented alone. Consequently, the treatment that will be explained from the first two goals can give
an idea of how the rest of the sequence is developed. Table 2 provides an overview of the TLS for the first two learning goals, demonstrating the progression in investigating and analysing EMI phenomena from an intuitive level of knowledge on EMI leading to analysis that differentiates between the experimental level and the interpretative level of EMI within Maxwell’s theory of electromagnetism.

<table>
<thead>
<tr>
<th>Driving Problem</th>
<th>Learning Goal</th>
<th>Scaffolding strategy</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why is the EMI interesting? Do you think this phenomenon is present in your everyday life?</td>
<td>1.- Understanding the point of studying EMI and its applications</td>
<td>Motivating the need to find out about EMI to understand how everyday appliances work. Helping students to understand how everyday appliances work, based on EMI</td>
<td>A.1 and A.2 allow students to explore the relationship between technological applications and EMI phenomena.</td>
</tr>
<tr>
<td>What causes EMI? When does an EMI phenomenon occur and when does it not?</td>
<td>2.- Become familiar with EMI phenomena and construct a primary explanatory model</td>
<td>Give the students opportunities to observe phenomena, make hypotheses and analyse results. Help students to distinguish between the empirical level (values and measurements) and the interpretative level that uses concepts such as variable electric current and magnetic field.</td>
<td>A.3 Students explore the characteristics of EMI phenomena. A.4 Students relate the EMI experiments to theoretical explanations. They explore the role of different physical magnitudes such as magnetic field, current, etc. A.5 Students interpret EMI characteristics on the current/time graph. A.6 Students construct an explanatory model of when EMI occurs. They contrast their hypothetical model against experimental results. A.7. Analysis of a wind-powered generator.</td>
</tr>
</tbody>
</table>

The teaching strategy is based on proposing tasks that give students the opportunity to develop and apply their new knowledge. In particular, the strategy proposed is based on ‘developing guided research’ which students can see make sense (Guisasola et al. 2008). The strategy aims to involve pupils in the construction of knowledge, bringing their activities close to what would be considered a ‘scientific treatment’ of problems. In this process there must be a balance between the freedom the students need to construct their ideas and the guidelines, necessary for students to make progress in the construction process, or accommodate their knowledge on grounds that they themselves understand.
One example of the initial activities that students work on in a group is as follows:

A.1 In the evenings, after spending a few hours on university work, you meet up with your friends in a practice room. You have formed a band and you are rehearsing to record your first demo.

a) Make a list of the things in the room.

b) Which of the objects on this list require electricity to work?

c) Do you know how some of these electrical appliances work? Look for information on the topic and decide which of the appliances on the list work, partly or totally, thanks to electromagnetic induction.

A.2 The majority of the things you put on the list need electricity to work. Do you know where this electricity comes from? Do you know how it is generated?

Students understand that many technological applications have a different source of electricity other than a battery and they are aware of the importance of knowing about the characteristics and laws that govern EMI (first learning goal). At this level, the relationship between electric current and induction phenomena is not particularly specific or intuitive. Information on EMI is structured at the lowest level of knowledge organisation. The unit has been sequenced from the lowest to the highest organisational level of the explanatory model and new concepts and laws are only introduced when a need for knowledge has been established. When the need for greater information has been established, students go on to do the following activities that include the second goal.

The second learning goal has two complementary components: experimental familiarisation at a macroscopic level concerning when EMI phenomena occur and more specific comprehension based on a first theoretical model that includes physical magnitudes studied in previous chapters on electromagnetism. The students’ comprehension has been organised in relation to the EMI phenomena relating, firstly, to the macroscopic effects that are measured using experimental apparatus such as a voltmeter and an ammeter. Secondly, students are helped to carry out a theoretical interpretation of the experimental measures. This strategy can be seen in the activity given below.

A.4. Let’s suppose that we vary the current $I_1$ that flows through a very long solenoid with radius $r_1$ and that, using an ammeter, we can measure the induced current $I_2$ in the outer circuit with resistance $R$ (see diagram). If we carry out the four experiments mentioned in the second chart, reason which of the conclusions a-d can be inferred from the aforementioned experiments:
EXPERIMENTAL FACTS

Experiment 1: Whilst the current $I_1$ is increased in the solenoid, the ammeter measures a negative current, meaning that $I_2$ circulates clockwise.

NB: The ammeter gives a positive reading when the current through it travels from the positive to the negative terminal.

Experiment 2: Whilst current $I_1$ remains constant, the ammeter measures a null current.

Experiment 3: Whilst current $I_2$ decreases in the solenoid (with half the growth rate of experiment 1), the ammeter measures a current that is half what is measured in experiment 1 and positive, meaning that $I_2$ circulates anticlockwise.

Experiment 4: If we use a solenoid that creates the same magnetic field inside as in experiment 1, but whose cross section is doubled, it is can be seen that $I_2$ doubles.

THEORETICAL EXPLANATIONS

a) The induced emf in the outer circuit surrounding the solenoid is proportional to the rate of change in the magnetic field inside the solenoid, $dB/dt$.

b) A stationary magnetic field does not give the induced magnetic field.

c) The induced emf on the outside of the solenoid is proportional to the solenoid's cross section.

d) A magnetic field, varying over time, inside the solenoid induces a field and an emf in the outer circuit surrounding the solenoid.

Student difficulties are well known in terms of interpreting the scientific concepts forming part of an explanatory model in different communication formats, such as formulas and mathematical graphs (Meredith & Marrongelle 2008). These authors demonstrate that students do not only need to have mathematical skills to understand the physical meaning of the equations and graphs, but it is also necessary for them to have opportunities to analyse specific situations where they are asked to relate equations, graphs and conceptual meanings. The activity presented below aims for students to be able to relate the graphs between magnitudes to the experimental phenomena analysed and to the explanatory model. This might seem to be a trivial point but it is highly important when students are capable of relating the experimental facts (macroscopic level) to the theoretical models composed of concepts and laws (microscopic level). The research found that this type of relationship posed a learning difficulty that was particularly resistant to change (Eylon & Ganiel 1990).

A.5 In relation to the experiments and the conclusions inferred from them in A.4, explain with reasoning what the following graph expresses:

\[
\text{Current} \quad I_1 \quad B_1 \text{ is proportional to } I_1
\]

\[
\text{Time} \quad I_2
\]

Given the situated nature of knowledge (Brown et al. 1989) exploring a single experiment on EMI, even though it analyses it in depth as enabled by the TLS development level, this might not be enough to
help construct a general explanatory model of the EMI. In order to reconcile the contextualisation vs generalisation dilemma, the sequence offers students more situations to analyse EMI and contrast the characteristics and the explanatory power of the constructed model. Exploring the different experimental facts leading students to analyse the different magnitudes that can influence the EMI and how its change is influenced over time (learning goal 2) can help students to construct a general explanatory model. This model will be looked at in greater depth and will be constructed within Maxwell’s formalism in the third learning goal, to be presented in future work.

Method

Context and Sample

The research described was carried out at the University of the Basque Country over a 2 year period. All first-year Engineering students (43 students in 09/10 and 61 students in 10/11) had previously completed two years of physics at high school. The physics syllabus at Spanish high school, for students aiming to subsequently take Science and Engineering degrees, covers mechanics and electromagnetism subjects during a 2-year period and with a level similar to A level courses in the UK. In engineering degrees in Spain, the number of male students exceeds the number of female students by far. In all groups the percentage of men and women is similar: 85% men and 15% women. The average student age is nineteen. The University of the Basque Country is a Spanish public university, meaning that the Government subsidizes 90% of the cost of the studies and the vast majority of students come from middle and upper-middle class families.

First-year Engineering students receive 3.5 hours of lectures and 2 hours in the lab per week for 14 weeks. The lectures were given by experienced teachers from the Physics Department. Electromagnetic induction and Faraday’s law are taught for 2 or 3 weeks of this course. The lectures and problem-solving taught electromagnetic induction phenomena, magnetic flux, induced electromotive force and Faraday’s law, Lenz’s law, electromagnetic force of movement. Teaching also analysed in detail how to use Faraday’s law to calculate the emf induced by variation in magnetic flux in situations where there is a time-variable magnetic field or when there is a variation in the area involved in the flux integral due to the movement of a circuit or part thereof. Around two lectures are devoted to explaining Faraday’s law.

Data collection and analysis

Two types of data were collected: a) pre and post written evaluation questionnaires; b) videotaping of student group carrying out some classroom activities. The pre and post evaluation questionnaires were collected over two academic years (09/10 and 10/11) from the two experimental classes. The aim was to obtain information on student reasoning trends in relation to the learning goals set in the sequence. Videos were collected on the discussions and solutions proposed by student groups when solving some tasks in the sequence.

Once the pre and post written assessment questionnaires had been prepared, we carried out a draft test with first-year course students, confirming that students had no problem understanding how the questions were formulated. The final versions comprise eight questions. We have included questions related to the TLS first and second learning goals in Appendix A. The questionnaire content validity and its relevance to the teaching goals are justified by the competency and professional expertise of the four teachers-researchers, qualified and experienced physics faculty members.

We videoed 4 groups (3 students in each group) who were selected based on the teacher’s recommendation and were representative of the classes in terms of gender, physics background and ability. Videotaping took place throughout the TLS. Videotaping lasted about 10-20 minutes and comprised the sequence task aimed at eliciting students’ reasoning about their understanding, targeting the first and second goals (for the complete protocol, see Appendix B).

Next, we shall focus on the process followed in order to analyze the answers. Analysis of the written questionnaires provides information on the first and second learning goals in accordance with the specific aims of each question, as described in the results section. The students’ written answers to the questionnaires were analysed qualitatively, using answer categories shown in other previous research.
(Mauk & Hingley, 2005; Meng Thong & Gunstone, 2008; Guisasola et al. 2011) as references; these categories were clarified and reformulated during the process (Kvale, 1996). Common tendencies have been identified in the students’ answers and representative examples of their answers have been included in this article. Research team members went on to analyze all questionnaires independently; the mean Kappa Cohen reliability coefficient was 0.87 for the questions. Any differences in the categories were resolved through discussion.

The recording part corresponding to the first two learning goals was done using a wind-powered generator model and comprised 5 questions. The students must identify the different parts that they can see on the apparatus. After analysing the apparatus, they must come up with a hypothesis on how it works. Afterwards, the model is set in motion and they must confirm their hypothesis, or not. As a final question, the students should mention other apparatus in addition to the turbine that work using EMI.

Data and findings

In order to analyse the effectiveness of this sequence for students to be able to achieve the set learning goals, a pre-post test was designed (Appendix A). This study shows the four questions matched up with learning goals 1 and 2. The goal of the pre-post test design was to study the control group students’ improvement in significant learning regarding EMI before and after implementing the didactic sequence we presented. This used Hake’s g index (Hake 1998) on the one hand and looked at how difficulties evolved relating to the learning goals on the other. Hake’s index shows that the gain in comprehension is significant if this index is equal to or greater than 0.1; we can see that this occurs in the four questions presented in table 4.

Table 4. Hake’s gain for each item in each year.

<table>
<thead>
<tr>
<th>Item</th>
<th>First year (N=41)</th>
<th>Second year (N=63)</th>
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<tbody>
<tr>
<td></td>
<td>Pre (% correct)</td>
<td>Post (% correct)</td>
</tr>
<tr>
<td>1</td>
<td>17.5</td>
<td>61.0</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>12.5</td>
</tr>
<tr>
<td>3</td>
<td>30.5</td>
<td>59.0</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>37.0</td>
</tr>
</tbody>
</table>

Item 1 and 2 investigate whether students recognise a situation where the electromagnetic induction phenomenon appears and whether they know the definition of electromagnetic induction (learning goal 1). In item 2, students have to identify and explain the electromagnetic induction phenomenon in real life applications (an induction hob in the pre-test and a magnetic levitation train in the post-test). In this second item, the answer percentages are low in the post-test and we think that this may be due to the specific case proposed for analysis (magnetic levitation train) that requires a high cognitive level. However, in the case of the video-recordings of activity A.7, students are capable of applying the concept of induction to the wind-powered generator case and reasoning correctly. For example, in a fragment from the interview with group 1, the students from this group reason correctly that the presence of the magnetic field is not sufficient to generate EMI.

76. **Julen:** You can see a support, can’t you? It’s got three coils that are connected up.
77. **Garikoitz:** You can also see some permanent magnets.
78. **Imanol:** The top base will move in the wind and so there will be induction in the lower coils.
79. **Edurne:** Why will the induction phenomenon appear?
80. **Imanol:** Because there is movement.
81. **Garikoitz:** Because the field is variable.

In this other example, group 3 recognise the apparatus they are looking at as a wind-powered generator. They are subsequently capable of relating other apparatus to EMI.

11. **Iker:** Look, there’s a little LED. The coils are in series, aren’t they?
12. Iñigo: You can see something else. Coils and some magnets.
13. Iker: Oh yeah.
14. Aitor: They are magnets. So what’s our hypothesis? What’s going to happen?
15. Iker: It’s a generator isn’t it? When this turns, the LED should come on. This is a wind powered generator working by electromagnetic induction.
32. Aitor: Can we think of any other examples from everyday life based on the same phenomenon?
34. Iñigo: What we saw at the start of the topic, the amplifying guitars, microphones, etc.
35. Iker: The dynamo was similar.
36. Iñigo: The dynamo on bikes for example. We’ve got to put it in the report.

The other two items explicitly investigate the causes of electromagnetic induction due to a variable magnetic field (item 3) and and/or movement of a conductor in a stationary magnetic field (item 4). Despite the fact that the g index is very high, in item 4 many students reason incorrectly using the concept of magnetic flux variation. Research has shown that this difficulty is hard to overcome (Zuza et al. 2012).

In prior research related to the learning difficulties, Guisasola et al. (2011) detected different difficulties, two of which are related to the first two learning goals. The first learning difficulty refers to that fact that students mistakenly reason that the stationary magnetic field or a continuous electric current are responsible for the electromagnetic induction phenomenon occurring. The number of references to this difficulty in the four items decreased by 58.7% in the post-test answers compared to the pre-test. Another of the difficulties shown by the research is that students give explanations on how everyday technological appliances work based on ‘common sense’ reasoning that is not founded on the explanatory model for EMI. For example, they confuse the induction phenomenon with the induced current or attribute erroneous relations between electric current and magnetic field. The number of times this difficulty is mentioned over the four items dropped by 45.9% after instruction.

Discussion and conclusions

The research into teaching physics proposes that electromagnetism avoids fast introduction of the concepts only based on their mathematical expressions (Chabay and Sherwood 2006). It particularly advises presenting the laws of electromagnetism indicating their validity range and where they stand in the hierarchy of explanatory capacity within classic electromagnetism (Bagno and Eylon, 1997). These suggestions are included in the learning goals for the constructed sequence.

Our findings suggest that most students progress from an “everyday thinking” conception of electromagnetic phenomena characterised by its inconsistent reasoning and upheld by intuition, towards an explanatory model of electromagnetic phenomena based on evidence and interpreting theoretical concepts such as variation of the magnetic field and magnetic flux. We have found that the majority of students abandon reasoning based on intuition when making hypotheses and interpreting experimental electromagnetic induction situations. In addition, students are capable of taking an interest in electromagnetic induction due to its technological applications both in everyday life and in industry (wind powered generator, induction hobs, etc.)

In terms of students’ comprehension in the role played by the magnetic field in electromagnetic induction, we found that the majority of students overcome the alternative conception of attributing induction to the magnetic field. Our findings support expectations that for students to develop explanatory models in line with the scientific theory, the curriculum and teaching strategies should be specifically guided. The current focus on concepts and laws presented by the majority of general physics text books does not fit with the learning path proposed in the sequence and does not support significant learning in electromagnetic induction.

However, in some matters (item 4) only a minority of students demonstrate adequate comprehension. This seems to indicate that the TLS example provided in this article is not sufficient to support the construction a solid comprehension of electromagnetic phenomena. It seems that in the case of induction by means of moving a conductor in a magnetic field, more activities should be proposed explicitly focussed on this difficulty. One of our concerns when designing activities has been calculating how many are necessary
for good comprehension. In the end, the number of activities was conditioned by the work load that our students can manage and the time available for the topic within the physics curriculum at our university. Maybe more activities aimed at analysing more induction situations might lead to a greater number of students with significant comprehension, above all for situations applying the theory to everyday life.

The greater implication of our work that we would like to discuss is the importance and feasibility of focusing instruction on mechanisms that relate experimental facts to the theory’s concepts and laws. These reasoning mechanisms are an important component of the scientific argument. Duschl and Jiménez Aleixandre (2012) proposed a perspective of science learning to teachers that represents participating in the scientific work’s epistemic goals, referring to knowledge-building goals. They propose looking beyond the students’ specific explanations and analysing the argument that upholds these explanations. In our work, we have demonstrated that students can provide explanatory mechanisms for the theoretical models that they use to interpret new phenomena and although they were occasionally not as accurate as required by scientific theory, they were sufficiently predictive within the theory. In addition, students do not need in-depth knowledge of mathematics to reason on the existence or nonexistence of electromagnetic induction and establish relationships between electric current and magnetic fields. The electromagnetic induction phenomena form complex systems whose analysis requires using reasoning with multiple variables and mechanisms explaining cause and effect. Therefore, it seems that there is no reason not to focus instruction on the mechanisms that they produce and predict electromagnetic induction.

References


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**APPENDIX A. Pre and post for the first and second learning goals**

<table>
<thead>
<tr>
<th></th>
<th>PRE</th>
<th>POST</th>
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<tbody>
<tr>
<td>1.-</td>
<td>Given the circuit in the diagram, can a situation exist where the diagram circuit lamp comes on without using the electricity network, a battery, a condenser or any other source based on charge separation? If you think it could, explain in detail how this might happen and on which physical phenomenon it would be based.</td>
<td>1.- Explain the phenomenon of electromagnetic induction in your own words, without using any formulas.</td>
</tr>
<tr>
<td>2.-</td>
<td>It is increasingly usual to find what are known as induction hobs in our kitchens. Explain in detail how they work.</td>
<td>2.- Maglev (magnetic levitation) trains levitate over the lines and travel at great speed avoiding friction problems. The simplified diagram of the apparatus that they use is shown. Explain in detail why these trains levitate.</td>
</tr>
<tr>
<td>3.-</td>
<td>We have a coil included in a circuit opposite a magnet at rest, as shown in the diagram. Will the galvanometer show any current? (If you use a law of physics in your reasoning, say which one).</td>
<td>3.- The lower diagram shows details of a solenoid that is crossed by a magnetic field. Do you think that magnetic induction occurs? Explain your answer in detail.</td>
</tr>
</tbody>
</table>
8.- A U shaped wire is sliding down a magnet as shown in the diagram, maintaining the angle to the magnetic field. Taking into account that both the wire and the magnet are conductors, does an induction phenomenon occur in the wire? Justify your answers.

8.- In the diagram we can see a copper disk turning in a magnetic field perpendicular to it. We want to know if electromagnetic induction will occur in this situation and we will use an ammeter to do this. We have put one of the terminals in the centre of the disk and the second rubs up against the outside of the revolving disk. Will the ammeter show a current is passing through?

**APPENDIX B. Activity A.7 for videotaping in the classroom**

A.7. Describe the apparatus after observing it and have looked at the photos below.

Figure. Wind powered Generator

1. Describe the role that each part of the apparatus plays in how it works. Make a hypothesis on how the apparatus works and its use.

2. Switch on the apparatus and contrast the hypothesis you made on how it works.

3. Explain the theory and laws this apparatus is based on.

4. Explain other applications that can be achieved with this theory.
Educational Use of Data from the CMS Experiment at the LHC

Thomas McCauley, Fermi National Accelerator Laboratory, Batavia, IL USA

Abstract

The Interactions in Understanding the Universe (I2U2) collaboration aims to bring cutting edge, hands-on physics to students (typically between 16-18 years of age). In order to accomplish this end we have created eLabs: web-based, student-led and teacher guided explorations of datasets from professional experiments, including the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC). I describe the current status of these activities, the positive feedback from the students, and the bright future outlook, including the potential to broaden these activities to a wider range of audiences.

Keywords: Large Hadron Collider, high-energy physics, public data, online educational tools

Introduction

The I2U2 collaboration has created several eLabs to enable students to explore datasets from large physics experiments such as CMS\(^1\) and the Laser Interferometer Gravitational Wave Observatory (LIGO)\(^2\). Students can also explore data from a network of classroom cosmic ray detectors. These “explorations” are modeled on the research process. Common among the eLabs are separate sets of milestones that guide students through their own research project. These assist the students as they pose a research question, explore the data and share results. The eLabs also provide data visualization and analysis tools, options to download data to a local machine, student logbooks and a facility to store, view and comment on plots. Ranging from short analyses (several class periods) to longer projects that students work throughout a term, eLabs can be adapted for use in classrooms, science clubs or other after-school activities.

I focus here on the CMS eLab\(^3\). The LHC at CERN currently provides proton-proton collisions at a center-of-mass energy of 8 TeV. The CMS detector is one of two general purpose detectors with a physics program that includes studies of quantum chromodynamics, electroweak, top, forward, heavy ion, and B physics, as well as searches for supersymmetry, exotic phenomena, and the Higgs boson. Recently the search for the Higgs boson has yielded an observation by the CMS and ATLAS experiments of a new boson with a mass of around 125 GeV (CMS, 2012) (ATLAS, 2012). The CMS collaboration has agreed to release a fraction of its data to the public for the purposes of education and outreach. This data forms the core of the CMS eLab.

In the eLab students can learn about how particle physicists analyze data, about detectors, and about fundamental particle physics. For example, students exploring the CMS eLab can analyze the kinematic properties of stable particles -the ones seen in the detector -to understand basic properties of the unstable parent particles that produced them and thus deepen the student’s knowledge of the fundamental building blocks of our Universe.

I begin by describing in more detail the datasets released to the public and next describe their usage in the CMS eLab.

Datasets

The datasets used in the CMS eLab have been made available to the public by the CMS collaboration for educational and outreach purposes. These proton-proton collision data produced by the LHC at CERN include more than 300k events containing pairs of electrons, muons and jets as well as W and Z bosons. The datasets are as follows, where those appearing in bold are already delivered and/or in use\(^4\):

- 2000 events each of J/ψ → μμ, J/ψ → ee

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1 http://cern.ch/cms
2 http://www.ligo.caltech.edu
3 http://www.i2u2.org/elab/cms
4 the data is available via the links found here: http://cern.ch/cms/content/cms-public-data

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• 2000 events each of $\Upsilon \rightarrow \mu\mu, \Upsilon \rightarrow ee$
• 500 events each of $Z \rightarrow \mu\mu, Z \rightarrow ee$
• 1000 events each of $W \rightarrow \mu\nu, W \rightarrow e\nu,$
• 100,000 events each of dimuon, dielectron, and dijet events in the energy range 2-110 GeV
• Since the time of this conference, the CMS collaboration has also agreed to release a number of Higgs candidate events to the public. Updates on this release can be found on the CMS webpage mentioned here.

There are several requirements and considerations to take into account during the preparation of the datasets. Firstly, the main users are students, supervised but teachers, studying the data in the context of educational programs like eLabs. Secondly, the data format must be easy to use and not require complicated software in order to read, visualize, and analyze the data. To fulfill this requirement, the data is released in an open, extensible, text-based format; we provide analysis tools via a web browser. Thirdly, the physics content of the datasets should not be restrictive in scope, to allow for flexibility; we want to be able to re-use and mix-up the data as needed. Lastly, the exercises based on the datasets shouldn’t be too difficult but shouldn’t be too trivial either. Students should not be expected to do a full physics analysis nor should they simply be able to “turn a crank” and produce answers.

Using the data students can learn about particle physics detectors and the common types of detector elements and techniques, from charged-particle tracking, electromagnetic and hadronic calorimetry, and muon detection. They can also learn about the production and decay of unstable particles such as W and Z bosons and J/ψ and _ particles. These de-cay into stable, detectable particles like electrons, photons, and muons and students can learn about identification and measurement of these particle’s properties. In the course of study students can also learn about invariant mass, determination of charge by curvature in magnetic field, and structure of the proton.

Usage

The goal of the eLab is that students learn about how physicists analyze data, learn about detectors, and about fundamental particle physics. eLabs are online data portals with analysis tools, supporting reference material, and access to a user community.

I2U2 provides a comprehensive online program for study of CMS data in eLabs. A schematic of the program can be seen in Fig. 1. This program is a “roadmap” of milestones. Milestones are provided that guide students through their own research project. These assist the students as they pose a research question, explore the data, and share results. Almost every step contains links to interactive content. For example, under “Get Started” the “Review particle types” link opens an interactive test where students are presented with displays of event types such as those with two muons, two electrons, and two jets.

After passing through the first two milestones students are invited to explore data, to “Figure It Out”. All of the datasets are available and with the aid of an online histogram tool various physical and kinematic properties such as invariant mass, transverse momentum, and missing transverse energy can be studied. One can also study correlations between these properties, for example cut on transverse momentum and see how it affects the invariant mass distribution. An example of an invariant mass plot can be seen in Fig. 2. One can see the peaks corresponding to the $J/\psi$ and $\Upsilon$. An indication of the controls available in the tool (e.g. cutting and zooming) can be seen in the figure.
Figure 1. Screen capture of the I2U2 CMS e-Lab project map. Online the project map is interactive and provides material at each stage.

Figure 2. Screen capture of a dimuon invariant mass spectrum using the I2U2 online histogram tool. Students can save their work (e.g., their plots) and continue along the milestones to “Tell others” and can for example, produce a research poster describing their results.

I2U2 also provides a browser-based event display (Hategan, McCauley, & Nguyen, 2012). The event display is written in JavaScript and works on any Web browser that supports HTML5 canvas. A screen capture of a $J/\psi \rightarrow \mu^+\mu^-$ event in the CMS detector can be seen in Fig. 3.

http://www.i2u2.org/elab/cms/event-display
Figure 3. Screen capture of a $J/\psi \rightarrow \mu \mu$ event in the I2U2 browser-based event display.

In the US hundreds of students have examined CMS data in eLabs: constructing invariant mass plots and exploring various quantities in histograms and plots. eLabs can be adapted for use in classrooms, science clubs, or other afterschool activities.

In addition to the eLabs the CMS datasets are also used in international educational programs in Europe, the United States and the rest of the world such as the International Particle Physics Outreach Group (IPPOG) masterclasses and QuarkNet (Jende, 2012).

**Discussion and Conclusions**

The CMS collaboration has generously released a fraction of its data to the public primarily for purposes of education and outreach. The I2U2 collaboration has produced an eLab based on this data to allow students to explore this data and learn about particle physics.

The open nature of the data and the tools provided allow for open and independent study of real LHC data to allow everyone with a passion for physics to share the excitement of the world’s largest science project.

In the future I2U2 looks to exploit further data releases and to continue to refine and improve the online tools and program contained in the eLab.

**Acknowledgments**

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Tablet Based Interactive GPS Textbook – A New Kind of an Educational Means

Jan Obdržálek, Institute of theoretical physics, Faculty of mathematics and physics, Charles university in Prague, Prague, Czech Republic and
Jiří Kofránek, Institute of theoretical physics, Faculty of mathematics and physics, Charles university in Prague, Prague, Czech Republic and
and Miroslav Svítek, Laboratory of biocybernetics and computer assisted learning, Institute of pathological physiology, First faculty of medicine, Charles university in Prague, Prague, Czech Republic and Department of control and telematics, Faculty of transportation sciences, Czech technical university in Prague, Prague, Czech Republic

Abstract

A tablet based interactive textbook explaining GPS principles will be presented. The explanation will be presented at varying level. Both Special and General Theories of Relativity are important here, the effect of GTR being even stronger than that of STR. Thus, so they are both verified any moment in everyday life. The geometrical construction of the unknown position by cross-section of three spheres is easy to understand even at the lowest level and it shows the utility of geometry. The presentation is an example of an everyday life “magic” device and use of its powerful properties in teaching and learning. The new technology brings new possibilities compared to classical books or notebooks, namely transferability, interactivity, flexibility, web connection. A complex cooperation of specialists in science (topics), programming (model, animation), pedagogy (scenario), fine arts (illustration and movies) with modern technology (animation, graphics) needed a multi-disciplinary cooperation and represents a particular cultural aspect. This program was presented on a tablet and in English. However, for use in secondary schools, translations to mother-tongue-languages are more recommended (the Czech version was prepared simultaneously and is also currently available).

1. Introduction

“Tell me, I’ll forget, show me and I may remember; involve me and I’ll understand” – this ancient Chinese wisdom is also confirmed by modern learning methods, sometimes called “learning-by-doing”, where simulation plays are widely applied. Simulation plays make it possible to test the behavior of the simulated object without any risk – for example, try to land with a virtual airplane or, as is the case of medical simulators, treat a virtual patient or test the behavior of individual physiological subsystems. Using simulation plays we can clearly explain the physical laws and principles of various technological devices.

The connection of the Internet and interactive multimedia environment with simulation models provides quite new pedagogical opportunities, particularly when it comes to explaining complex interconnected relationships, active exercising of practical skills, and verifying theoretic knowledge. The old credo of Jan Amos Comenius “Schola Ludus” – i.e. “school as a play” [1] pioneered by this European pedagogue as early as in the 17th century finds its application in the incorporation of multimedia educational games in training courses.

Thus, we used these new developments to combine interactive graphics, simulation games and an easy to use distribution of educational materials using the Internet to teach base ideas of physics [8, 9] and medicine to explain some complicate processes in the human organism [5, 6]. We managed to develop an interactive Internet-oriented Atlas of Physiology and Pathophysiology [4, 7] combining explanations with the use of interactive moving graphics within educational simulation games.

New possibilities for the interactive e-learning education arose with the availability of new hardware – tablets being even more convenient than classical notebooks. GPS yields possibilities for new applications – not the classical navigation only, but e.g. interactive multimedia guides for historical sights (where the position data initiates the describing just that sight close to the user’s location).
Framework for those applications is a part of planned project *Tablet based interactive GPS textbook*. It can be seen as the part of telematics – a result of convergence and progressive synthesis of navigation, telecommunication technology and informatics based on a synergism of them allowing a *new kind of an educational means*.

*Satellite navigation* has become an important part of modern navigation using on-line tablet based information systems for travelling through big cities, finding relevant on-line information for local resources, etc. The current constraint of huge navigation equipment increase could be also seen in low accuracy in counting the real position. The problem is possible to solve either with help of difference reference stations, or by advanced GNSS (Global Navigation Satellite Systems) signal processing [3, 11] or by combination of current GPS and future GALILEO systems.

The differential method is based on transmitting the GNSS correction signal through radio channel. Fig.1 shows the accuracy achieved by absolute and differential methods, where we used for our experiences absolute measurements of PPS (Precise Positioning Service) by very cheap GPS equipment GARMIN III personal navigator. Such precision is necessary for interactive textbook especially for educational means in big cities.

![Figure 1. The GPS accuracy for different modes [10]](image-url)
2. Methods

2.1 Requirements for tablet based GPS applications

2.1.1 Performance parameters definition

The following performance parameters were defined for tablet-based applications:

- **Reliability** – the ability to perform required function under given conditions for a given time interval.
- **Availability** – the ability to perform required function at the initialisation of the intended operation.
- **Integrity** – the ability to provide timely and valid alerts to the user when a system must not be used for the intended operation.
- **Continuity** – the ability to perform required function without non-scheduled interruption during the intended operation.
- **Accuracy** – the degree of conformance between a platform’s true parameter and its estimated value, etc.

Following communications performance parameters quantify telecommunication service quality:

- **Availability** – (i) Service Activation Time, (ii) Mean Time to Restore (MTTR), (iii) Mean Time Between Failure (MTBF) and (iv) VC availability.
- **Delay** – is an accumulative parameter affected by (i) interfaces rates, (ii) frame size, and (iii) load / congestion of all in line active nodes (switches).
- **Packet/Frames Loss**.

2.1.2 Performance parameters for tablet based interactive textbook

Among the individual interactive tablet applications using GNSS the following may be emphasized together with required performance parameters:

- **Navigation of the cars in a transport network** – from the point of view of performance parameters, it is a matter of coverage with a signal, time lag in on-line navigation, requirements as for the exactly working maps of an entire geographical area, requirements on the speed of information processing, both within a mobile unit and the processing center, as well as minimization of the delay when establishing the position – TTFF – Time to Fix Face.
- **Monitoring the movement of persons in a city infrastructure** – from the point of view of performance requirements, it is a matter of transmission and central processing of large amount of information from resources with various accuracies, fast identification of individual personal tablets, sophisticated information processing in the center.

2.1.3 GPS performance parameters

Taking into account the presented methodology we can define GPS performance parameters as follows:

- **Coverage** – the percentage of time availability of sufficient number of satellites everywhere in the world and in anytime
- **Global average of GPS coverage**: 99.9 %
- **The GPS coverage for the worst case**: 96.9 %
- **Availability** – the probability that selected point is covered by satellites with usable signals
- **Global availability average of GPS**: 99.85 %
- **The GPS availability for the worst case**: 83.92 %
- **Reliability** – the percentage of time in which the horizontal error does not exceed the predefined limit
• Global reliability average of GPS: 99.97 % for 500 m and 1 year
• The GPS reliability for the worst case: 99.79 % for 500 m 1 year

Integrity – the probability to provide timely (not late than TTA – time to alert) and valid alerts to the user when a navigation system exceeds the position error limit (AL – alert limit)

Safety – signals specification is secret and it is available only for trustworthy experts, detailed risk analyzes, all components of navigation system (receiver, SW and HW, critical applications, digital maps, etc.) are certified

2.1.4 EGNOS performance parameters

EGNOS (European Global Navigation Overlay System) distributes information through 3 GEO satellites:
• integrity message,
• correction data for ionosphere refraction,
• distance measuring signal.

GPS/EGNOS performance parameters can be summarized as:
• accuracy 1 m - 2 m,
• integrity alert 6 s (message is sent in case the alert error limit is exceeded),
• continuity 10-7,
• availability 99 % (in case accuracy, continuity and integrity is correct).

2.2 Testing of performance parameters

General methodology for testing of GNSS performance parameters [2] is shown on Fig. 2.

Figure 2. Testing of performance parameters for tablet-based applications

Testing process of tablet based interactive GPS application consists of following steps:
1. definition of initial conditions for tablet application (block 1);
2. definition of optimally operating tablet application (block 3);
3. disturbance statistics definition – internal disturbance of tablet application (block 6, disturbance of whole set of tested tablets), disturbance of GNSS signal (block 7) and external disturbance (block 8);
4. activation of tested tablet application (block 5);
5. testing of measured tablet application with simulated GNSS signal (block 4) for all defined situations/scenarios (initial conditions – block 1) with goal to cover all suitable situations;
6. real testing of selected (available) scenarios;
7. conformity assessment of output data from appropriate (tested) tablet application and output data from model (optimally operating) application for defined initial conditions and defined disturbances;
8. measurement results processing for protocol of measurement and final assessment of performance parameters guarantee (block 2);
9. performance parameters guarantee must be statistically verified on a sufficient number of measurements to be able to guarantee monitored properties in defined statistical parameters.

2.3 GPS principle education textbook

The satellite navigation belongs to the broadly used technologies today being due to commercial pressure quite “user friendly” and inexpensive.

The use of GPS seemed to be promising for multimedia tablet performance explanation for following reasons:

- Whereas GPS is well-known, its principles are mostly unknown and paradoxical: accuracy of decimetres reached by comparing the distances of tens of thousands kilometres?
- The explanation of principles GPS could, as a by-result, attract the interest of a reader to the
donable
descriptive geometry used for the formulation of problems in space and time,
numerical methods necessary to get on-line solutions quickly enough,
theory of relativity.
- Use of GPS represents an everyday approval of both special and general theory of relativity and shows that they are far not so abstract as it were suspected.
- The interactivity of a tablet education textbook enables explaining on quite different levels (from a primary school to university).

A tablet based device can be used as an interactive GPS textbook for explaining the basic principles of satellite navigation. We present a new kind of an educational means that can be used within a real tablet based application.

The explanation of finding the position can be presented at the secondary school level, without using differential calculus.

From physics, both Special and General Theories of Relativity (STR, GTR) are mentioned and their use explained. Namely, following STR, the frequency of moving object is slightly, but remarkably lower than the frequency of the clock staying in rest, whereas – in the opposite – following GTR, the frequency of a clock staying in a weaker gravitational field (22 000 km above the Earth) becomes higher than that of the clock staying on the Earth.

The effect of the GTR is stronger than the contribution of the STR. Those effects were presented among other verifying any moment in every day’s life both relativistic theories.

The geometrical construction of the unknown position by cross-section of three spheres is intuitively simple and should be discussed and explained in details to show the utility of geometry.

The interactive program is presented on a tablet in English. However, for the use on the secondary school, mutations in mother-tong-languages are more recommended.
Fig. 3 and Fig. 4 represent the examples of possible human-machine interaction (HMI) of tablet based education application.

2.4 Methodology of making interactive educational applications

Making an interactive educational application needs a multidisciplinarity. Many specialists must cooperate to reach good result, namely

- domain specialists (physicist; specialist for GPS; teacher),
- graphics – interactive computer graphics,
- programmers,
- good manager.

Figure 3. Example of education software HMI

Figure 4. HMI example of mathematical tool

WCPE 2012, Istanbul, Turkey
As a first tool, Adobe Flash with Adobe Captivate have been used. It is not supported by tablets but it is supported by the tablet notebooks with full Windows 8.

As a more convenient language, HTML5 was chosen and by Adobe Flash CS 6 transferred into a format applicable for Apple iPad.

3. Data and findings

Our program enables an explanation at different levels. An example is accessible at web site http://www.physiome.cz/GPS.

Our application has been tested on two groups of users: 78 students and teachers of the medical faculty of university, and 24 attenders of a University of third age (x):

- 1,28 % (0 %) new already the principle of GPS,
- 100 % (100 %) understood the principles after passing this program,
- 19,2 % (41,7 %) found the mathematical explanation too complicated or were not interested in math,
- 92,3 % (87,5 %) appreciated this program as profitable,
- 0 % (0 %) needed to include some other part to be explained.

4. Discussion and conclusions

4.1 From enthusiasm to technology and multidisciplinary cooperation

Far gone is the time when a handful of enthusiasts, excited about the new possibilities of personal computers sold during the eighties, were making their own tutorial and education programmes. Computers, development tools and the methods of the software creation process are much more powerful today, their numeric and graphical possibilities are enormous, high-speed internet surrounds the entire planet and represents huge potential in the modern education process. Authors must be today much more experienced and educated.

The creation of high-quality software capable of utilizing the huge potential offered through the information and communication technologies of today, still depends on the enthusiasm and hard work of individuals. It is a complicated development process, involving all kinds of professionals and experts:

- experienced teachers, whose script is the base for high-quality tutorial application;
- system analysts responsible for the creation of simulation models used in simulation games;
- art designers creating the outer look and visual shape;
- information specialists (programmers) “stitching up” the application together into its final shape.

To make sure that the work of all kinds of specialist is efficient, it is necessary to have many interconnected development tools and methods which make the cooperation between all involved members easier and helps them overcome the differences and barriers in their fields. A great deal of hard work and effort needs to be put in to master these tools, but the final results are well worth it.

The tutorial software creation process is slowly becoming a blend and a combination of pedagogical experiences and the creativity of enthusiasts. It is mostly work for specialized teams using highly specialized development tools and it is beginning to look more and more like an engineering project.

4.2 From GPS to GALILEO

At the end of the paper we would like to compare GPS and GALILEO systems in both competitive and co-operative point of view:

Galileo – GPS competition:

- GPS III, currently being researched, will match or surpass Galileo’s accuracy;
- The EU wants to be more than the consumer and partner in the background;
- The EU dislikes the US’s reduced accuracy policy;
• They want to improve the existing service;
• They want fully civil satellite navigation;
• They want to have a guarantee that the service is always available.

Galileo – GPS co-operation:
• Political issues put aside, GPS and Galileo will cooperate;
• Galileo will complement the existing GPS in accuracy and availability;
• However, Galileo will also be able to run independently;
• All the satellites will be able to communicate with each other;
• Existing GPS-receivers will be able to make use of Galileo.
• We believe that this designed tablet based an interactive GPS textbook can be used as a new kind of an educational means for the public because it yields a synergy between mass-market tablet based applications and a special education tool about principles and performance of GNSS.

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References
A Novel Approach to Encourage Students’ Independent Thinking in Physics Laboratory

Rajesh B. Khaparde, Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research
V. N. Purav Marg, Mankhurd, Mumbai 400088, INDIA

Abstract

The objectives of physics laboratory courses include fostering conceptual understanding and development of several important cognitive, psycho-motor, attitudinal and affective abilities. In most of the Indian colleges and universities (and probably at many other places all over the world) the usual practice of performing a set of experiments in a ‘cook-book’ mode, seldom help students achieve the objectives of the physics laboratory courses and develop the abilities and skills required to become a successful experimental physicist. This paper describes the details of an instructional approach designed and being followed by the author over the past few years, to encourage students’ independent thinking in the physics laboratory. This instructional approach encourages students active participation, independent thinking and offers an opportunity to learn ‘how to think scientifically’ during traditional physics laboratory courses without major ‘curriculum’ and ‘content’ changes. Here, ‘guided problem solving’ approach is adopted by combining ‘problem-solving’ and ‘guided design’ modes of instruction. In this approach an experiment is presented as an ‘experimental problem’ with well-thought procedural instructions. During a typical laboratory session, first an introductory demonstration is presented by mentors to each group of a few students separately for the first 20 minutes as a prelude to the problem and the remaining laboratory time is made available for students to independently ‘solve’ the experimental problem. The paper also illustrates the approach by describing a familiar experimental problem and the demonstration on ‘Electromagnetic damping’ with some details of the experimental arrangement, which is being used by the author for training of students and teachers at the introductory university level.

Keywords: Physics laboratory courses, training in experimental physics, scientific thinking, guided problem solving, experimental problem, demonstration, procedural instructions

A Novel Approach to Encourage Students’ Independent Thinking in Physics Laboratory

1. Introduction

A considerable amount of time is devoted to physics laboratory training in India at the higher secondary, B. Sc. and M. Sc. levels. During a typical physics laboratory course students are made to perform a large number of experiments in a ‘cook-book’ mode. Most of the experiments performed in teaching laboratories are of ‘verification or determination’ type. The number of experiments keep changing but the mode of conducting laboratory sessions more or less remains the same from its introduction at the higher secondary till the M. Sc. level.

It is observed that the students are given detailed instructions either orally in the classroom or in the form of written sheets. Teachers/instructors provide lot of information to the students in order to complete the experiment in the specified time. This deprives the students of the opportunity to learn by themselves and provides very little scope for students’ self-planned and independent experimental work. The laboratory training seldom helps a student achieve the objectives of the physics laboratory courses and develop abilities and skills required to become a successful physicist. A large number of teachers and researchers from all over the world have studied and reported on similar concerns and issues related to laboratory courses, which include Barbenza, (1972); Boud, (1980); Duggan, (2002); Gott, (1995); Gott, (1999); Hofstein, (1982); Khandelwal, (1989); and Kruglak, (1960).

The laboratory training is indeed an important and indispensable part of teaching of physics and therefore many teachers and researchers have worked on various aspects of laboratory training and developed various instructional approaches, experiments and demonstrations. Some major efforts related to the

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activity based teaching of physics include, Laws, (1999); McDermott, (1996); Redish, (2003); Sokoloff, (2004); Sokoloff, (2007); and Sokoloff, (1997). It is important to note that each of these approaches has its own place, role, importance and problems with the feasibility or use in the regular laboratory training.

In this paper, an attempt towards reformulating existing experiments and demonstrations and development of novel instructional approach for the physics laboratory training is reported. The instructional approach presented here encourages students active participation, independent thinking and offers an opportunity to learn ‘how to think scientifically’ during traditional physics laboratory courses without major curriculum and ‘content’ changes. (Khaparde, (2009))

2. A novel instructional approach

In this approach ‘Guided problem solving’ method is adopted by combining ‘problem solving’ and ‘guided design’ methods of instruction. Here, an experiment is presented as an ‘experimental problem’ with guiding procedural instructions. During a typical laboratory session, first an introductory demonstration is presented to each group of a few students separately by the facilitators / mentors for 20 minutes as a prelude to the problem and then remaining laboratory time is made available for students to independently ‘solve’ the experimental problem. Each demonstration is carefully designed to help students solve the given experimental problem by introducing either the basic conceptual understanding required for the problem, the experimental method/technique or the experimental arrangement.

Here, the demonstration serves a specific role of illustration or observation of an event, a concept or principle. The demonstration performed by a teacher or students in a small group in the laboratory help students to recall and refine their conceptual understanding, which students may need to apply in the given experimental problem. Every demonstration, which was designed had a smooth flow of activities, questions, answers, discussion and explanations and was presented in an interactive manner and the interaction between the students and the mentor was triggered through observations, questions and related discussion. The demonstration was presented to stimulate thinking in students and develop cognitive abilities like observation, application, synthesis, interpretation and inferring.

Some key features of the instructional approach are described below:

a) What is an experimental problem ?

A problem is often seen as a stimulus situation for which there is no ready response and the solution calls for either a novel action or a new integration of available actions. Similarly, an experimental problem may be seen as an experimental situation in which one cannot see a ready solution and one needs to perform operations involving combination of conceptual understanding, procedural understanding, scientific processes and skills to arrive at the desired solution.

Here, each experimental problem is presented as a collection of simple smaller experimental stages, which are interdependent or hierarchical in time. In each stage, the students are given simple tasks. The tasks are woven in succession so that the whole problem unfolds through them and students following them are guided stepwise toward the solution, making definite progress through each step. Thus, students solve the experimental problem in graded stages. Each stage may have a different focus, may involve a different type of experimental activities and may aim at different learning outcomes.

b) Guided problem solving

The author employed ‘guided problem solving’ method in which an experiment was presented as an experimental problem to the students. The students were given a carefully designed individual handout for each experimental problem, the corresponding instruction sheet and the answer paper. In this approach, students were guided through the handout to think of and design their own method, to carry out measurements, to analyze data and were thus guided and trained to understand and solve experimental problems. Here, the task or the expected final stage was clearly stated and explained but the detailed instructions, which a student may follow to reach to the desired state were not given. Instead, some starting hints and instructions were given, which may guide the students towards the solution of the problem.
c) Free laboratory ambiance
This approach encouraged a ‘free laboratory ambiance’ where students were made to think about the procedural aspects of experimentation, with a least possible guidance from the teacher. Students were encouraged to carry out self-designed and independent experimental work. The ‘free laboratory ambiance’ does not refer to an open ended or exploratory type of experimental activities. The idea of ‘free laboratory ambiance’ was that the students were informed about the final outcome of each part of experimental work, but they were given autonomy with respect to choice of variables, choice of range of values of variables, use of instruments and experimental techniques, method of data handling and analysis etc. For example, in an experimental problem if students are asked to study the relation of incident intensity to the output current of a photodetector, then they were given a starting instruction on the possible use of inverse square law for establishing linearity, asked to identify the necessary apparatus with their detailed specification, given some hints for the experimental arrangement, and asked to identify the dependent, independent and control variables, construct a fair test, identify the sample size, understand the types of the variables involved and thus in short design the detailed procedure. Further, they were asked to choose sensible values of variables or parameters, proper range and interval between different values of these parameters. They were then asked to record the desired data and analyze the data using tables and graphs to derive meaningful and expected results. Thus, in this approach the students were provided a freedom with respect to finer procedural stages, but were still guided with respect to the approach or a possible method of solving the problem.

d) Format of presentation
Students were expected to read the student handout and understand the necessary details of the problem. They were expected to understand the use of different apparatus and the related warnings or precautions. Students were expected to broadly use the procedural instructions, design an appropriate method on their own, answer the questions, carryout the necessary measurement, record the data, carryout the necessary analysis of the data and derive the results.

e) Student handout
Students were individually given carefully designed handout for each experimental problem. Students were expected to work independently with guidance provided in graded stages through the handout. The description of the experimental problem given in the handout did not follow ‘cook-book’ format, instead it took the student away from mechanically followed instructions to a more self designed and student oriented experimental activities. The students were given a brief conceptual introduction to the problem, the necessary description of apparatus and the experimental setup and the theoretical basis through the handout. The students were given the procedural instructions with an intention to ‘guide’ them but only with respect to a possible method of ‘solving’ the experimental problem.

f) Procedural instructions
Students were given ‘open’ procedural instructions, which guided them to a right start and encouraged them to think on various aspects of experimentation. These instructions guided students’ thinking at the same time offered a room for independent thinking, designing and planning of actual procedures. These ‘open’ instructions were not like ‘cook-book’ type of procedural instructions where students are ‘spoon-fed’ with actual procedural stages without any scope for independent thinking and designing.

For example the instructions included, “You may have to use law of Malus; identify the independent, dependent and control variables; vary the parameter X in convenient and appropriate steps and study its effect on parameter Y; plot an appropriate graph to determine Z; record the necessary data to study the inter-dependence of X and Y; determine the value of X graphically”. The instruction “determine the value of X graphically” informed students that they were expected to think of and plot an appropriate graph and determine from it the value of the parameter X, but it did not inform them about what the nature and the scale of the graph should be, which parameters should be plotted, how the parameter X is determined, and so on.
g) Experimental arrangement

Students were provided with the required apparatus and were given a free hand to work in the laboratory. They were also given some extra apparatus and instruments to choose the most appropriate instrument for a particular measurement. Students were supposed to assemble various instruments and make the necessary experimental arrangement on their own.

Students were also given an instruction sheet specifically prepared for a problem. This instruction sheet had information on the use of different instruments and apparatus, the adjustment of the apparatus and the necessary safety instructions and warning. The user manuals of various instruments published by the manufacturers were made available to the students on request.

h) Reporting of laboratory work

Students were not observed by a teacher while they worked on the given experimental problem and hence were not evaluated on the basis of direct observations by the teacher. Instead, students' performance was only verified or assessed on the basis of the report of their work in the answer paper. This aspect of the instructional approach effectively reduces the teachers intervention into the students work and encourages self designed independent experimental work by students. The students' answer paper is treated as the only record of their laboratory work and their solution to the problem. Students are expected to record and report every procedural step they adopted during the experimental work, observations, readings, method, detailed data analysis, final results and inferences in the answer paper.

i) Preliminary questions

Students were given a set of preliminary questions (often referred to as pre-lab questions) for each experimental problem. Each student was required to independently answer these questions prior to the actual experimental work. These questions were based on the basic concepts, laws, principles, their applications, experimental techniques, use or care of apparatus and a variety of procedural aspects related to the design, measurement and data handling. These preliminary questions played a very important role in preparing the students to efficiently carryout the experimental work.

j) Essentials for experimental physics

It was felt that there are some important aspects related to measurements, statistical treatment of data, graphical representation and analysis of data, significant figures and error analysis which are essential tools of experimental physics. Students should have a good knowledge and understanding of these before taking the course in experimental physics. In this approach a detailed reading material on all these aspects was prepared and made available to the students in advance. Students were expected to read this material and develop the basic knowledge about all the aspects. During the initial stages of the laboratory training, a considerable amount of time was spent on developing students understanding and confidence with respects to use and regular practice of all the essentials for experimental physics.

k) Role of the teacher

Another aspect of the approach is minimal intervention by teachers. Students were not offered any direct advice from the teacher with respect to procedural aspects in solving the experimental problem instead the teacher played a role of a silent observer. The teacher provided minimal guidance to the students. Students were expected and allowed to take their own decisions about procedures and measurements. Sometimes, the teachers were requested to coerce students to independently plan the procedural details. Teachers helped students in understanding the use of instruments or even the theoretical basis of the problem.

The approach described above is illustrated below through a set of sample experimental problem and associated demonstration on electromagnetic damping, which the author has developed for the laboratory training of undergraduate physics students.
3. Sample experimental problem on electromagnetic damping

In this experimental problem, an aluminum disc is mounted on a horizontal axle around which a cord is wound (Figure 1 and Figure 2). A slotted mass hangs from the free end of the cord. If this slotted mass is released, it accelerates due to the force of gravity. There is a torque on the disc and it undergoes angular acceleration. A pair of cylindrical magnets is placed symmetrically with respect to the disc. If the slotted mass is released in the presence of the magnets, the slotted mass and the disc initially accelerate and soon the disc reaches a constant angular velocity and the slotted mass falls with a terminal velocity. The constant angular velocity of the disc indicates rotational equilibrium of the disc where the torque due to the weight is balanced by an opposite damping torque. There is a frictional torque at the supports, but it is relatively small. The main opposing torque arises due to electromagnetic damping.

![Figure 1. Schematic diagram of disc and magnets assembly](image1)

![Figure 2. Photograph of disc and magnets assembly](image2)

The terminal velocity, with which the weight falls, depends on different parameters like the geometry and dimensions of the disc and the axle, conductivity and magnetic permeability of the material of the disc, the magnitude of the mass attached at the end of the cord, magnetic pole strength of the pair of magnets, position of the magnets, the spacing between the magnets and the disc, and the frictional torque. Two pairs of identical magnets with the same size and shape but of different pole strengths $B_1$ and $B_2$ are given. Also, a velocity measurement unit with a detector was provided to measure the velocity of falling mass.

A student working on this experimental problem was expected to: a) observe the motion of the disc and the falling weights with and without the magnetic field, b) perform necessary measurements to study the variation of the terminal velocity of the falling weight with the magnitude of the mass attached, for a given pair of magnets (with a fixed spacing between each magnet and the disc), c) replace the pair of magnets with another pair, keeping all other parameters the same, and again study and record the variation of the terminal velocity with the mass attached and d) determine the ratio of the magnetic pole strengths of the two pairs of magnets and estimate the frictional torque due to the frictional force at the supports.
4. **Sample demonstration on electromagnetic damping**

The objective of the demonstration was to illustrate the phenomenon of electromagnetic damping and explain the dependence of electromagnetic damping on the conductivity of the material of a conductor in which eddy currents are set up and on the strength of the magnetic field. The experimental setup (Figure 3) consisted of three hollow cylindrical pipes, identical in dimensions and made of aluminum, copper and PVC, respectively. Three small solid (rare earth/ceramic) magnets marked C₁, C₂, and C₃ were used. All the three magnets were identical with respect to their dimensions and masses but had different magnetic pole strengths. The magnet marked C₁ was completely de-magnetized by heating it and was not at all a magnet.

![Figure 3. Photograph of the complete experimental setup for the demonstration](image)

In this demonstration one observes the fall of magnets through three different hollow cylindrical pipes made of aluminum, copper and PVC. The motion of the magnets through aluminum and copper pipes is damped on account of electromagnetic damping caused by induced eddy currents in the pipe. The eddy currents are induced due to the motion of the magnets through the pipe. The motion of these magnets through the PVC pipe is un-damped, since no eddy currents are set up in this case. The motion of the completely de-magnetized magnet C₁ through all three pipes was un-damped.

5. **Conclusions**

During a laboratory course, the mode in which students work with the given set of experiments is the most important factor in deciding the effectiveness of training in experimental physics. It is felt that there should be a scope for students’ self-planned and independent experimental activities during physics laboratory training. The emphasis should be on students’ own initiative, on moving them away from ‘cookbook’ instructions and from spoon-feeding. The approach based on the ‘guided problem-solving’ with an innovative format of presentation, described above yielded better learning and overall results compared to the traditional method. This approach successfully guides students to think of and design their own method, to carry out measurements, to analyze data and thus imparts training to solve experimental problems. This instructional approach is being used by the author in various programmes for students and teachers in India. It is noted that this approach helps students for the development of a) Procedural understanding as well as conceptual understanding and practical skills; b) Experimental problem-solving abilities and independent working habits; c) Higher-level cognitive abilities like designing, predicting, observing, classifying, application, synthesis, interpreting and inferring and d) attitudinal aspects and affective abilities like, creativity, curiosity, interest and open-mindedness.

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6. Acknowledgements

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References


Beyond Recipe-Based Practical Exercises: Towards a Better Future?

D. Clerk and D. Naidoo, School of Physics, University of the Witwatersrand, Private Bag 3, WITS 2050, Johannesburg, South Africa

Author Note: douglas.clerk@wits.ac.za; deena.naidoo@wits.ac.za

Abstract

Traditional “recipe-based” practical exercises may have a high degree of outcome predictability but, because they absolve the student of a great deal of thinking, they arguably have a low degree of value as learning experiences. Practical exercises could instead become problem-solving exercises, where the student must devise a method as well as generate an answer to a question, given prior warning only of the broad outcome of the task. A common objection to this sort of exercise is that realistically, they can only be performed by students after the relevant ‘theory’ has been covered. This can present a difficulty for service courses where large groups of students must often be catered for. Because all students in a given group would, of necessity, have to perform the same exercise simultaneously, economic and logistic obstacles, such as the cost of purchasing and also the problems of storage of large quantities of equipment can be seen as prohibitive. In this paper, we present an exercise that provides a potentially good learning experience and can easily be performed by first year students without detailed procedural instructions. Not only this, but the apparatus for this exercises is cheap to obtain and relatively easy to store, hence the objection mentioned above becomes invalid.

Introduction

According to Woodley (2009, p. 49), “practical work is part and parcel of what teaching and learning in science is all about”. She goes on to state that “[m]ost practitioners would agree that good quality practical work can engage students, help them to develop important skills, help them to understand the process of scientific investigation, and develop their understanding of concepts” (p. 49). Those who take practical work’s necessity as axiomatic and its efficacy as guaranteed would certainly agree with this. Indeed they may possibly criticise these statements as not being emphatic enough. To continue, the American Association of Physics Teachers (1998) recognises five goals of the introductory physics practical:

I. The Art of Experimentation: The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations.

II. Experimental and Analytical Skills: The laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis.

III. Conceptual learning: The laboratory should help students master basic physics concepts.

IV. Understanding the Basis of Knowledge in Physics: The laboratory should help students to understand the role of direct observation in physics and to distinguish between inferences based on theory and on the outcomes of experiments.

V. Developing Collaborative Learning Skills: The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavors.

A critical look at actual laboratory programmes might however reveal something less than optimal. For example, it is difficult to see how the traditional ‘cookbook’ practical can achieve any of these goals as they completely absolve the student of the necessity to think – all the student has to do is follow a set of instructions. Students find this type of exercise not only unchallenging, but also unedifying. (Belcher, 2001), (Hanson, 2000)

Also, according to constructivist wisdom, ‘conceptual understanding is not so much an outcome of experimental work as an essential prerequisite for its successful operation.’ (Solomon, 1992, p. 93) One
wonders how practical work can promote conceptual understanding if it must be there first so that practical work can be meaningful.

The first year practical programme at our university is a case in point. For reasons that have more to do with logistics than with good instructional practice, in any one week a student will perform a practical exercise which is allocated according to a roster. In the following week the exercise next on the schedule will be performed - and so on for the rest of the year. There is seldom any connection between the practical exercise being performed and the physics theory being taught at a given time of the year except by chance. The practical programme becomes essentially independent of the theoretical programme – each practical exercise stands alone. This makes it absolutely necessary that the students be given detailed instructions - literally a recipe to follow – to enable them to perform the exercise at all - as they do not necessarily have any theoretical background when performing a given exercise. It also brings to mind Solomon’s (1992) statement about conceptual understanding being a prerequisite to practical work – for most of the year that prerequisite is simply absent from the picture. In some cases the students perform a practical at the beginning of the year and then only deal with the relevant theory at the end. In other cases, the converse will apply and students will be performing exercises at the end of the year where the theory is covered at the beginning, and is for all intents and purposes long forgotten.

The given reason for this state of affairs is thus: in order to guarantee that all students perform any practical exercise shortly after the theory has been dealt with, they would of necessity need to all be doing the same exercise at the same time. As some of our service courses cater for large groups of students (exceeding 800 annually in the case of engineering) this would constitute an unwarranted expense and would create difficulties with respect to storage because of the large number of sets of apparatus that would be needed. The sheer quantity of equipment is regarded as prohibitive, hence the roster system currently and historically in force. The problem here is that didactic considerations are being knowingly sacrificed for logistic – there is no claim that there is any didactic advantage to be gained from the roster system, merely that there is no other economic way of doing it. Admittedly, some of our instructors do sincerely believe that this is a didactically sound way to proceed – arguing that the students are learning physics by doing the practical exercises. I however have my doubts; if conceptual understanding really is a prerequisite to successful performance of practical work, as per Solomon (1992), then practical work performed in the absence of conceptual understanding amounts simply to ‘going through the motions’.

In this paper we argue that the rationale for the current roster system may be based on faulty logic. Apart from the didactic desirability of the roster system being debatable, there exist several practical exercises – perhaps enough for an entire curriculum and if not, for at least part of one – that require apparatus that is so cheap and compact that all students, even in large groups, can do them simultaneously. Acquisition and storage of the apparatus is not a problem – in fact a significant portion of it is generic equipment that would be in stock anyway, such as metre sticks, retort stands, clamps etc. We present here one such exercise to illustrate our point. This exercise has what we like to call a high ‘didactic payload’ – in other words, there is good potential for learning because of what students are required to do during the exercise. Particularly important is the potential in this sort of exercise as a way to teach problem-solving.

Given that a problem is a task with an algorithm that is not at the outset known to the problem-solver and that problem-solving is hence the creation, or discovery of that algorithm (Martinez, 1998), the ‘cookbook’ practical logically cannot teach problem-solving, as the algorithm (i.e. the ‘recipe’) is given to the students. If however, the students are required to devise their own experimental method as part of the exercise, an element of problem solving then enters the picture. This makes necessary certain considerations: When a practical exercise is performed in the absence of a recipe – i.e. where the devising of a method is part of what the student has to do – it is essential that students must be familiar with the relevant theory (Solomon, 1992), and that they have prepared for the exercise. Otherwise the exercise becomes worse than a cookbook practical as the student would be utterly lost and would in all probability learn little or nothing. (Most university lecturers would probably maintain that any student not familiar with theory already covered and unwilling to do preparation should not be at university anyway.) In addition, there is good potential for this exercise to achieve at least some of the goals of practical work according to the American Association of Physics Teachers (1998).
The exercise we discuss here requires the student to measure the track separation of a laser disc. It would be suitable for any first year physics course involving physical optics and perhaps of particular interest to student teachers who might be teaching physical optics at high school level. In this exercise the student is faced with a collection of apparatus and the instruction to measure the track separation of a laser disk. Most students are now familiar with CD’s and DVD’s and should have an idea that the track separation is very small. They might wonder what sort of instrument they will be given to take the measurement with. Provided that diffraction and the diffraction grating has been dealt with in lectures and in tutorials, the student - with a modest amount of luck, some judiciously dropped hints from the lecturer and maybe some ‘Googling’ – should come across the idea that the laser disc is in fact a diffraction grating. At this point the student can figure out that measuring the separation of the interference maxima can lead to the calculation of the line separation of any diffraction grating and hence to the track separation of the laser disc. Hereafter all that remains is the logistics of actually taking the measurements.

The procedure is as follows: First the student needs to ‘calibrate’ the laser – i.e. establish the wavelength of the laser light. This is necessary as the lasers being used are likely to be laser pointers and the wavelength is unlikely to be obtainable from a label. For this purpose, a standard diffraction grating, the laser to be used and some metre sticks – as well as sundry stands and clamps are all that’s required. The laser is shone through the diffraction grating as shown – note that the metre stick is actually used as a screen (Figure 1) to make measuring separations between maxima more convenient.

$$\tan \theta = \frac{x}{D}$$

With the separation between two of the maxima (sensibly between zero and one!) i.e. $x$ and between the ‘screen’ and the diffraction grating i.e. $D$, both known, the diffraction angle $\theta$ can be calculated, using: Where $x$ is the separation between adjacent maxima and $D$ is the distance from diffraction grating to metre stick (i.e. screen).

$$m\lambda = d \sin \theta \Rightarrow \lambda = \frac{m\lambda}{d}$$

Now that the diffraction angle is known, the wavelength of the laser light can be calculated using

Where $d$ is the line separation of the diffraction grating and $m$ is the order number of the interference maxima.

Once the laser has been calibrated, the diffraction grating is replaced with the laser disk. Here, the student is faced with a problem to solve: the disc is backed with a reflective layer and will not transmit the laser light. There are two solutions to this problem: either remove the reflective layer or else use instead a CD ‘blank’ which has never had the reflective layer applied. These can be found in bulk packs of CD’s which can be bought in retail outlets. The other solution is to place the metre stick acting as the screen just behind the laser – light from the laser is then reflected back onto the metre stick ‘screen’. Either of these solutions works well – the ‘blank’ CD is perhaps the best option technically speaking but making the student solve the problem has some added didactic appeal.

The (new) diffraction angle is determined as before using the measured separation between two interference maxima (again sensibly zero and one) – i.e. $x$ - and the distance between the laser disc and the metre stick. The track separation is determined as in Figure 2:

The value typically obtained by first year students, working in the complete absence of a recipe, is close to the ‘book’ value of 1,6 μm (Jones, E. R. & Childers, R. L., 1993) – (see Figure 2.)

The numbers used in the calculation shown in Figure 2 are authentic, and took only a few minutes to measure.

The process described above is not a ‘tall order’ – I have personally run this exercise several times with complete success with both first year students and teachers in training. They do not, as may be supposed, regard the apparatus with paralysed horror when faced with the prospect of devising their own procedure. Instead they have always treated the exercise as a welcome challenge and have always been able to get reasonably accurate measurements.
The cost of the apparatus is minimal: most of the items needed are already in stock in a properly equipped physics laboratory – the only item that will almost certainly have to be brought in specially would be the laser discs. I have never had any problem obtaining enough of these at no cost at all. The existing stock of lasers might need to be increased, but laser pointers can be bought at prices that can hardly be regarded as prohibitive. Storage of the items between exercises is also no problem as they are compact and take up very little space.

**Discussion and Conclusion**

Faced with the questionable didactic efficacy of cookbook practical exercises, we should surely be looking for better alternatives for our first (and other) year programmes. Exercises do exist which are not prohibitively expensive and could therefore be done by all students of even quite large groups simultaneously. With some effort it should be possible to devise a large enough collection of such ‘shoestring experiments’ that at least a portion of a first year practical programme could be run as problem solving exercises that were directly linked to the theoretical programme. A question we need to address is ‘what stops us?’ One possible answer to this could be that there is a shortage of research data to support what we are proposing here. Three issues arise from this: the first is that a logical next step would be a proper evaluation of this type of practical exercise. The second is that supporting research data does exist – Allie, Buffler, Kaunda & Inglis (1997) report that this form of practical is currently being used at the Physics Department of the University of Cape Town and ‘has greatly enhanced the overall learning experience of our students.’ Thirdly, it may not be useful to take the attitude that in the absence of hard data, we should not proceed. After all, given a programme purported to train runners, that effectively absolved the trainees of the need actually to run – would we really insist on hard research data before we started looking for a better option?

Another – potentially unpopular - answer to the question that must be considered: perhaps we don’t want to change existing programmes for purely emotional reasons. All the effort and expense that went into creating them in the first place – and the fact that they currently allow teaching staff to operate in something of a comfort zone that they would be understandably reluctant to leave. If there is any validity in this point, we need to think very carefully about what we are doing and about possibly making some changes.

PS: During a recent tea-room discussion, a colleague recently suggested that there is a danger that the ‘shoestring’ practical would, because of its low-budget image, reduce the motivation of students to perform properly during practical exercises. Students, he was suggesting would not be inclined to take the shoestring practical seriously. Our answer to this is twofold: In the first place, there is no necessity to tout these exercises as being in any way inferior to the more conventional exercises involving big budget equipment. Arguably they are actually superior in that they fulfil their purpose better than the traditional exercises and at a lower cost. In the second place, experience teaches us that the traditional practical exercise has its flaws too, quite apart from those already mentioned. Historically, the performance of students during conventional practical exercises has in fact frequently been ‘suboptimal’. I can personally attest to the rather widespread use of ‘recycled’ measurements during laboratory exercises in my own first year of physics, back in 1971.

**References**


*WCPE 2012, Istanbul, Turkey*


**Figures**

\[
\tan \theta = \frac{x}{D} = \frac{126}{297} = 0.424 \quad \Rightarrow \quad \theta = 22.9887 \approx 23^\circ
\]

\[
d = \frac{m\lambda}{\sin \theta} = \frac{1 \times 653 \times 10^{-9}}{\sin 22.9887} = 1.672 \times 10^{-6} \text{ m} \quad (\approx 1.7 \mu\text{m})
\]

('Book' value: 1.6 \mu\text{m})
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Students’ Strategies in Solving Physics Problems 
Questionnaire Research

Marie Snetinova, Zdenka Koupilova and Jaroslav Reichl, Charles University in Prague, The Secondary School of Telecommunication and Broadcasting Technologies

Author Note
Marie Snetinova and Zdenka Koupilova, Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic.

Jaroslav Reichl, The Secondary School of Telecommunication and Broadcasting Technologies, Prague, Czech Republic.

This research was supported by the Charles University Grant Agency 374711.

Correspondence concerning this article should be addressed to Marie Snetinova, Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague, V Holesovickach 2, 180 00 Prague 8, Czech Republic.

Abstract

Many students – not only at high schools – often solve physics tasks without deeper understanding of physics context and the solving often turns into a simple “mathematical manipulation” with formulas. Therefore, we have prepared questionnaire for high school students and teachers. The aim of the survey was to find out if students use any approved steps that help them with problem solving. Another goal for the research was to gain students’ opinion about the importance of problem solving. Two questionnaires for students were composed – one containing open format questions only and the second with open format questions as well as rating scale questions (concerning use of chosen problem solving strategies). The teachers’ questionnaire had only open format questions. Categorization of the students’ strategies was partly inspired by a research carried out by Ogilvie (2009). The participants of this questionnaire survey were high school students in the last four classes (students at the age of 15 to 20), who are attending physics lessons during their study, and their teachers. The questionnaire study is a first part of a more extensive qualitative research concerned with the problem solving in physics education. Methodology and results of the described research are presented in the contribution. Based upon the results of the study we show the steps that students, according to their own opinion, use in the process of problem solving.

Keywords: physics education, problem solving, strategies

Students’ strategies in solving physics problems – questionnaire research

Problem solving in physics has a long tradition in the Czech high school education system, which is proved, among others, by a large number of problems in physics textbooks and problem collections, e.g. Lepil (1995), Žák (2011). Unfortunately, many students often struggle with many difficulties when they are faced with physics tasks. They solve the tasks without deeper understanding of physics context and the solving often turns into a simple “mathematical manipulation” with formulas.

What causes these obstacles? Do students use proper methods and techniques to solve physics tasks? Do students know the appropriate methods how to improve their problem solving skills? To answer these and other questions, we have prepared a questionnaire survey described below.

The presented research has a qualitative character and its main goal was to find out high school students’ perspective on problem solving in physics. Moreover, the questionnaire also investigated what techniques students claim to use in solving physics tasks, and if there are any approved steps that help them with the problem solving. The students’ questionnaires were accompanied by a teachers’ questionnaire that investigated teachers’ opinion on students’ strategies in problem solving. The survey is a part of more extensive research concerned with developing of problem solving skills in physics education. It follows the literature search presented in Snetinova (2011).
Methodology of the Research

Foundation

The presented questionnaire survey was based on a research described in Ogilvie (2009). The main goal of the survey was to find out if students – according to theirs as well as teachers’ opinion – use more frequently the “limiting” or the “expansive” strategies. This division is borrowed from Ogilvie (2009).

According to Ogilvie (2009), as limiting strategies are marked those techniques that “… may work well for well-structured, end-of-chapter exercises, but they begin to fail as the problem become more complex”. The expansive strategies “… can be readily applied to more ill-structured challenges, and these strategies have also been identified as characteristic for expert problem solving approaches”.

Participants

The respondents of students’ questionnaires were students from all four last grades of Czech high schools, where physics is taught. The questionnaires were completed by 773 students from schools. The teachers’ questionnaire was filled in by 17 high school teachers.

Description of the Questionnaire Survey

Students’ questionnaires. The survey contains two questionnaires for students (marked S1 and S2). The questionnaire S1 (408 respondents) consisted of one rating scale question, which investigated how often students use problem solving strategies stated in Table 1, and of five open format question. The questionnaire S2 (365 respondents) consisted of only five open format questions. The list of all open format question is shown in Table 2.

Strategies described in the Table 1 are divided into two categories – limiting strategies (marked L1 – L4) and expansive strategies (marked E1 – E5). As we mentioned above, the limiting strategies can be good enough for students to gain correct solution of some physics tasks, but they are not appropriate for developing problem solving skills. On the other hand, the expansive strategies are often used by problem solving experts (Ogilvie, 2009).

Both types of the students’ questionnaires were design similar on purpose and they contain even three identical questions. The main difference lies in the form (open format or rating scale) of the question that investigated students’ problem solving strategies.

Teachers’ questionnaire. The teachers’ questionnaire served as a supplement of the main part of the questionnaire survey, which were represented by the students’ questionnaires. The main goal of the teachers’ questionnaire was to find out teachers’ views on the strategies that students use in solving physics tasks.

The questionnaire contained 3 open format questions. The questions concerned techniques how students solved physics tasks and time that teacher dedicated to the solving of physics tasks and problem solving strategies during lectures. List of teachers’ open format questions is stated in Table 2.

Main Results and Discussion of the Research

Before interpretation of the acquired data, it is important to remind that the research had a qualitative character and therefore every single student’s or teacher’s mentioned idea is important for the evaluation.

Students’ Problem Solving Strategies

One of the main goals of the students’ questionnaire survey was to determine which strategies and methods students indicate that they use in solving physics problems. Nine strategies were described in the questionnaire S1 (see Table 1) and students should stated how often they use these strategies. The results are shown in Figure 1.

It is evident that students often stated they use so called limiting strategies. These strategies can often be successful in solving physics tasks, but it is necessary to teach students how to use the expansive strategies as well to develop their problem solving skills.
It can be seen from Figure 1 that the most often mentioned strategy is *Listing known and unknown quantities*. This is a relatively unsurprising result, because Czech students are taught since primary school to write this list just below the assignment. Other noticeable result is using the Rolodex equation matching. For many students it can be the easiest way how to obtain a result, but it is totally unsuitable for improvement of their problem solving skills and understanding the physics concepts. Buffler and Allie (1993) claim that use of this strategy can be caused by “... the instructor may mention what principles or concepts are being applied, but generally only writes down the associated equations” approach when illustrating physics concepts by solving particular problems.

The second students’ questionnaire S2 asked the question about students’ problem solving strategies as well (see Table 2, questionnaire S2, question 1). The question had an open format character. The most frequently mentioned strategies and the number of respondents are stated in Table 3. The strategies are arranged according to the frequency of responses.

It can be seen that the most often stated strategy in the questionnaire S2 is Rolodex equation matching (93 of participants). On the other hand, the majority of expansive strategies were stated only by a small number of respondents.

The most frequently mentioned strategy – except the strategies described in Table 1 – is *Thinking about the problem* (29 of participants). However, this method can partly overlap with other strategies, for example *Concept first* or *Real situation*. This special category of students response was established for such answers in which students did not state exactly or in more detail how they think about the problem.

**Teachers’ Questionnaire**

The teachers’ questionnaire was filled in by 17 participants. The experience with teaching was up to 5 years for 8 teachers and more than 5 years for 9 teachers. Most teachers stated that they dedicate more than 25 % time to the solving of physics tasks in their lectures. According to teachers’ statements, solving of physics tasks is used at the end of discussed physics topics, to show application in practice, to practise learned matters, as well as in examination.

In lectures, teachers try to teach students how to solve physics tasks. The results of the survey show that they use following methods:

1. Solving several typical tasks on the board at the end of every physics topic;
2. Discussing with students about single steps when solving physics tasks;
3. Pointing out the typical mistakes;
4. Highlighting what is important to watch out for during problem solving.

In teachers’ view, students often use limiting strategies to solve physics tasks. The most frequently mentioned strategies were:

1. Looking for similar tasks;
2. Rolodex equation matching;
3. Combining of numbers from the assignment;
4. Trying to drill as much tasks as possible.

All of these strategies were mentioned at least by two teachers. The teachers did not state the strategy *Listing known and unknown quantities*. Teachers probably do not consider this as a problem solving strategy. From our teaching experiences as well as from results of this survey, we believe that students often write the list of knowns and unknowns during solving physics tasks.

From the teachers’ answers it was obvious that both the methods teachers use and strategies students use in teachers’ view do not depend on teachers’ experience with teaching or their age.
Other Open Format Questions from the Students’ Questionnaires

Below are stated results gained from the questionnaire survey. These results are completed by several original students’ answers. We believe that all results can be interesting and useful in practice.

1. Students should know why some strategies or methods are required or recommended from them. Many students understand the solving of physics tasks only as one of several ways of marking. Therefore, it is important even for teachers themselves to think about the purpose of solving tasks in physics and what skills it develops.

   Student: “It was often recommended to me to draw pictures. But what is the purpose of this if I don’t know any idea about the situation and I can’t draw?”

   Student: “When I’m solving a task, it helps me to know what the point of doing it is.”

2. Students should have a feeling that they can gain correct solution by their own when solving physics task. Harper (2006) writes: “Many students believe that when you read a problem, you either know how to solve it or you don’t. The instructor may appear to know exactly how to solve a problem the moment (s) he lays eyes on it. One way to address this mistaken belief might be to make the process more transparent to the class.”

   Student: “In my opinion, the most common approach that is used in explaining some task is: to take a look at the task and immediately know what’s going on. But I can’t use this approach.”

   Student: “Our teacher solves the task by herself and she thinks that we understand the steps. But it is not true.”

3. Other interesting observation is that students do not realize that solving physics tasks is not only about getting the correct answer. It is important for students to be able to formulate their thoughts – either on paper or verbally. Teachers have then an opportunity to consider, if the students’ thoughts are correct and they can draw students’ attention to their shortcomings.

   Student: “I try to solve the task by my guess, but teachers mostly want some formulas.”

Future Plans

The presented questionnaire survey is only one part of a more extensive research inquiring into solving quantitative physics tasks. The survey will continue by creating of methodical materials for high school teachers and worksheets for students that should contribute to development of students’ problem solving skills. In the next year, these materials will be integrated into physics lessons at several Czech high schools.

Conclusion

Students – not only at high schools – often struggle with many difficulties in solving physics tasks. The main goal of the presented questionnaire survey was to find out what problem solving strategies students claim to use and what their view on problem solving is generally. The teachers’ questionnaire served as a supplement of the students’ questionnaires.

Whole survey showed that the most frequently mentioned methods are so called limiting strategies (Ogilvie, 2009). These strategies can be good enough for students to gain solution of some physics tasks, but they are not appropriate for developing problem solving skills.

On the basis of the described questionnaire survey, methodical materials will be prepared. The materials will consist of detailed instruction for high school teachers and worksheets for students.

References


WCPE 2012, Istanbul, Turkey


**Table 1.**

*Description of problem solving strategies in rating scale question of questionnaire S1*

<table>
<thead>
<tr>
<th>Short name of strategy</th>
<th>Description of strategy used in the questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1: Listing known and unknown quantities</td>
<td>“After reading the assignment I make a list of known and unknown quantities.”</td>
</tr>
<tr>
<td>L2: Rolodex equation matching</td>
<td>“I try to select an equation largely because the equation has the same variables that are listed in the assignment.”</td>
</tr>
<tr>
<td>L3: Prior examples in text or lecture</td>
<td>“I try to find similar task (in textbook, notes or elsewhere).”</td>
</tr>
<tr>
<td>L4: Prior experiments in lecture</td>
<td>“I try to remember if we did some experiment similar to the task during lecture.”</td>
</tr>
<tr>
<td>E1: Sub-problems</td>
<td>“I try to solve the task step by step and divide it into smaller sub-problems.”</td>
</tr>
<tr>
<td>E2: Real situation</td>
<td>“I try to imagine the problem in a real situation.”</td>
</tr>
<tr>
<td>E3: Concept first</td>
<td>“First I think about the ideas and physics concepts involved in the problem.”</td>
</tr>
<tr>
<td>E4: Rational thought</td>
<td>“First I solve the task in my mind and then I do arithmetic.”</td>
</tr>
<tr>
<td>E5: Diagram</td>
<td>“I try to draw some diagram (sketch, chart ...) to every task.”</td>
</tr>
</tbody>
</table>
**Table 2.**

*List of open format questions from all three used questionnaires*

<table>
<thead>
<tr>
<th>Questionnaire S1</th>
<th>Questionnaire S2</th>
<th>Teachers’ questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is your biggest problem during problem solving in physics?</td>
<td>Do you have any proven steps you use during problem solving in physics? What methods do you use if you don’t know how to solve the problem at first sight?</td>
<td></td>
</tr>
<tr>
<td>Is there anything that helps you with solving physics tasks?</td>
<td>To what do you pay attention during solving physics tasks?</td>
<td></td>
</tr>
<tr>
<td>What is – according to you – the purpose of solving physics tasks?</td>
<td>What is – according to you – the purpose of solving physics tasks?</td>
<td></td>
</tr>
<tr>
<td>Do you think that you can use these approaches even in other situations? In which ones?</td>
<td>Do you think that you can use these approaches even in other situations? In which ones?</td>
<td></td>
</tr>
<tr>
<td>Which steps were recommended or shown to you to help you solve physics problems?</td>
<td>Which steps were recommended or shown to you to help you solve physics problems?</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.**

*Frequently mentioned methods and strategies from the questionnaire S2*

<table>
<thead>
<tr>
<th>Mentioned strategies</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolodex equation matching (L2)</td>
<td>93</td>
</tr>
<tr>
<td>Listing known and unknown quantities (L1)</td>
<td>36</td>
</tr>
<tr>
<td>Diagram (E5)</td>
<td>32</td>
</tr>
<tr>
<td>Thinking about the problem</td>
<td>29</td>
</tr>
<tr>
<td>Cooperation</td>
<td>28</td>
</tr>
<tr>
<td>Reread the assignment several times</td>
<td>24</td>
</tr>
<tr>
<td>Trying to combine “everything with everything”</td>
<td>23</td>
</tr>
<tr>
<td>Real situation (E2)</td>
<td>19</td>
</tr>
<tr>
<td>Prior examples in text or lecture (L3)</td>
<td>19</td>
</tr>
<tr>
<td>Postponement of the task for later</td>
<td>19</td>
</tr>
<tr>
<td>Concept first (E3)</td>
<td>5</td>
</tr>
<tr>
<td>Sub-problems (E1)</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 1. Answers to the question: “How often do you use strategies mentioned below?” from the questionnaire S1.
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The ESTABLISH Project and an Assessment of its Impact on Students

Martina Kekule and Vojtech Zak, Charles University in Prague

Author Note
Martina Kekule and Vojtech Zak, Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague

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Correspondence concerning this article should be addressed to Martina Kekule/Vojtech Zak, KDF MFF UK, V Holesovickach 2, 180 00, Prague, Czech Republic. E-mail: martina.kekule@mff.cuni.cz, vojtech.zak@mff.cuni.cz

Abstract
The paper deals with the European project ESTABLISH, which supports inquiry based science education (IBSE). Particularly, the article is focused on an assessment of an impact of the project on students. The assessment is provided in the areas of: intrinsic motivation, development of students’ cognitive skills, appreciation of the importance of science and technology in society, and students’ inclination toward taking up careers in science. For collecting evidence two questionnaires will be used. The first one is based on Intrinsic Motivation Survey and it is aimed at assessing students’ interests, their perceived choice and usefulness of implemented learning units. Each learning unit consists of several lessons which are designed within the project. The questionnaire is aimed at collecting feedback after each learning unit. The second questionnaire assesses the project’s impact on students’ attitudes toward science and technology and on their knowledge about nature of building up science knowledge. The questionnaire consists of two independent parts: an adopted part of the ROSE (The Relevance of Science Education) questionnaire and the Epistemological Beliefs Assessment for Physical Science. This questionnaire is intended for collecting data from students who completed at least three learning units. In the article, results of a pilot study are presented. Particularly, we discuss reliability and validity of the tools. Because of translations of tools into native languages of participated students, we pay lot of attention to the discussion of the content validity. After carrying out the pilot study, final versions of questionnaires will be available in several European national languages. Then the tools can be used not only for the purpose of the project, but also in the common school practice.

Keywords: IBSE method, motivation, epistemological beliefs, physics education

Introduction
The objective of the project ESTABLISH is the dissemination and use of an inquiry-based teaching method for science with second level students in Europe by creating authentic learning environments, involving all stakeholders to drive change in the classroom.

Over the course of the project, a number of ESTABLISH Teaching and Learning Inquiry Based Science Education (IBSE) units are developed and adapted for use in classrooms across Europe. The ESTABLISH group includes eleven European countries and more than sixty partners that work together to encourage and promote the more widespread use of Inquiry-Based Science Education (IBSE) in second level schools.

The ESTABLISH consists of several workpackages: selection of core teaching and learning IBSE units; involvement of strategic partners; localisation, adaptation and pilot evaluation of teaching and learning units; teacher education; assessment the implementation of ESTABLISH on student learning; evaluation; dissemination; management.
This article is focused on collecting feedback from students, what is the main aim of the workpackage 6 (assessment the implementation of ESTABLISH on student learning) of the project. This workpackage assesses the impact of the project on students’ attitudes towards science and students’ learning skills. Particularly, the tasks of this work package are:

- Assessment the impact on intrinsic motivation for learning science taking into account various pre-conditions, e.g. gender, cultural differences.
- Assessment the impact on student’s (both boys and girls) appreciation of the importance of science and technology in society.
- Assessment the impact on student’s inclination towards taking up careers in science.
- Collecting evidence to assess the development of students’ analytical skills and learning processes. It is important here to determine if there is a gender effect to this development.

In order to find out the impact of the project stated above, we have used already existing tools, particularly questionnaires. The choice of questionnaires is the topic of the first paragraph. Then the description of created tools follows and the second part of the article presents results of the pilot study.

**Questionnaires**

**Assessing intrinsic motivation**

For this purpose we have chosen The Intrinsic Motivation Inventory (IMI) which is a measurement device intended to assess student’s subjective experience related to a target activity in laboratory experiments. The instrument is based on the Self-determination theory developed by Ryan and Deci (for example Ryan, Deci 2000). It is probably the only instrument, which is developed for measurement of motivation concerning experimenting in science, so it has not been matter of the choice. The instrument gives altogether six subscales scores. The dimensions are: participants’ interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure and tension, and perceived choice while performing a given activity. As the authors presents at a web page devoted to the instrument (Ryan, Deci, 2000): “The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation; thus, although the overall questionnaire is called the Intrinsic Motivation Inventory, it is only the one subscale that assesses intrinsic motivation, per se. As a result, the interest/enjoyment subscale often has more items on it that do the other subscales. The perceived choice and perceived competence concepts are theorized to be positive predictors of both self-report and behavioral measures of intrinsic motivation, and pressure/tension is theorized to be a negative predictor of intrinsic motivation. Effort is a separate variable that is relevant to some motivation questions, so is used it its relevant. The value/usefulness subscale is used in internalization studies, the idea being that people internalize and become self-regulating with respect to activities that they experience as useful or valuable for themselves”. A construction of the instrument allows choosing only some dimensions which we want to measure along. Because of limited time of each student for fulfilling feedback questionnaires, we have chosen only three dimensions which are the most relevant: interest/enjoyment, perceived choice, value/usefulness. As the interest/enjoyment scale is the only feature which measures the motivation on itself, it has been necessary to choose the dimension. The dimension pressure/tension measures the negative impact on intrinsic motivation. During choosing the next two dimensions we have taken into account the context of implementing IBSE method into schools. Firstly, students’ investigation supposes students’ self-management during performed activity, that is why we have included dimension value/usefulness into the created tool. Secondly, taking lessons by IBSE will be probably for many students a new way of their learning, so that it could be difficult for them to estimate their perceived competence well. Thirdly, activities designed within the ESTABLISH project and doing during the IBSE lessons allow some choices for students what to be focused on. That is why we decided to measure whether the students perceive the chance for their choice and we have omitted the dimension pressure/tension. The relevant part of the questionnaire for upper secondary school students contains 25 statements each with a 5-point Likert scale from ‘True’ to ‘Not true’.
Assessing appreciation of the importance of science and technology in society, assessing inclination towards taking up careers in science

This issue has been studied by two international projects targeted to students at lower secondary school (age 13 and 15). It is the SAS project (Sjøberg, 2000 a,b) that was followed by the ROSE project (Schreiner & Sjøberg 2004) where students from both developed and developing countries participated in. The SAS and the ROSE – small scale studies – are emerging from the ‘bottom’ instead of from governments and their key motivation is shed light on students’ perceived relevance of science and technology. The topic deals with two terms “interest” and “attitudes”, where according to Gable and Wolf (1993) interest shows students’ preferences for doing a particular activity, and attitudes are characterized as feelings which students have towards an object. The ROSE project is focused on measurement both these constructs (Schreiner & Sjøberg 2004). The questionnaire consists of 9 parts: ACE –What I want to learn about, B – My future job, D – Me and the environmental challenges, F – My science classes, G – My opinions about science and technology, H – My out-of-school experiences and I – Myself as a scientist. The construction of the questionnaire and its characteristics (validity and reliability, Schreiner & Sjøberg 2004) enables to use only some part in order to find out what is the matter of our interest. Because of the time limitation for the fulfilling the questionnaire by each student, we have decided to use only two parts of the tool, namely part F and G. From the content point of view, these parts are the most relevant for collecting the impact of the project on students’ attitudes to science and technology. Each part contains 16 statements, each with a 4-point Likert scale from ‘Disagree’ to ‘Agree’. The part F is focused on students’ perception of their science classes, their self-confidence in their own abilities, their choice for taking up career in science and technology. The part G probes different aspects of how the students perceive the role and the function of science and technology in society.

Assessing students’ cognitive development

The design of the project aimed at collecting the evidence about the impact on students´ learning processes with the emphasis on analytical skills. This general objective can include assessing several constructs. Mainly, we have considered issues about learning styles, analytical skills, reasoning, and about students’ epistemological beliefs about science. The firstly mentioned construct is characterized by Keefe (1979) like “characteristic cognitive, affective, and psychological behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment”. A model of learning process and learning styles has been done by several researchers and a lot of tools designed for identifying the learning styles have been developed. The available tools with the estimation of Cronbach’s alpha higher than 0, 75 are listed below:

- Gregorc style Delineator, author A. F. Gregorc, acronym GSD
- Learning Style Inventory, author R. Dunn, K. Dunn, G. E. Price, acronym LSI
- Learning and Study Strategies Inventory, author C. E. Weinstein, D. R. Palmer, A. C. Schulte, acronym LASSI
- Motivated Strategies for Learning Questionnaire, author T. Garcia, P. R. Pintrich, acronym MSLQ
- Inventory of Learning Processes-Revised, author R. R. Schmeck, E. Geisler-Brentstein, acronym ILP-R
- Learning Skills Profile, author D. A. Kolb, R. E. Boyatzis, C. Mainemelis, acronym LSP

These tools measure various aspects of learning styles, somewhere focused on the affective and somewhere on the cognitive domain. However, during the project we would like not just only find out students’ learning styles, but also we would like to identify some changes and show a positive impact of the project on students. Here the issue about “the right” learning style arises. As the construct of learning styles shows rather the diversity of approaches to learning, from the perspective of education it would be difficult to state that possible changes are positive ones. Because of the reason, we turned out our attention to the impact on reasoning and analytical skills or epistemologies about nature of science. For our purpose we have consider these available tools:

- Sternberg Triarchic Abilities Test by J. Sternberg
The Epistemological beliefs assessment for physical science (EBAPS) by A. Elby, J. Frederiksen, Ch. Schwarz, B. White

The ESTABLISH aimed at the support of implementing IBSE into the schools. Although it is not the first project which brings such a support (see for example project POLLEN), still in many countries participated in the project, this teaching method is not much common. So it is possible to assume that many students will take such a lesson for the first, second time. In contrast to teaching by explaining, the inquiry method should show to students what way science and scientist works. This is strong reason why we have decided to focus on students’ epistemologies about nature of science. For collecting evidence about this issue, we could choose from three tools: VASS, MPEX, and EBAPS. The first and second tools have been developed for college students. The latter is aimed also at high school students. It has been also a reason why we have chosen the questionnaire. Another and the strongest reason is connected with the form of the instrument items. The authors of the questionnaire have taken into account the implicit aspect of the beliefs and proposed the items form reflecting this assumption. The items are mostly presented as an interview among students and by choosing from several alternatives, where a tested student indicates with whom s/he agree. This feature increases very probably the validity of the testing. EBAPS probes students’ views along five non-orthogonal dimensions: structure of scientific knowledge, nature of knowing and learning, real-life applicability, evolving knowledge, and source of ability to learn. As each student can devote approx. 45 min to fulfilling a questionnaire, we had to take into account this time restriction and adapt only a part of the questionnaire. We have chosen dimensions, which are tightly connected with knowledge: structure of scientific knowledge, nature of knowing and learning, evolving knowledge.

The tools for assessing impact of the project on students

Altogether students’ assessment will be ensured by 2 types of questionnaires:
- “fast“ feedback after the learning unit
- impact of more learning units

Each type of questionnaires exists in a version for lower (marked B, about 12 to 15 years old, ISCED 2), and upper (marked A, about 16 to 19 years old, ISCED 3) secondary schools.

Questionnaire 1A, 1B

These questionnaires are intended to be used as a fast” feedback after each learning unit and they will be assigned immediately after each lesson unit (at the end of the lesson). The questionnaire is the adapted part of Intrinsic Motivation Inventory. It takes about 10 minutes to complete this questionnaire.

Questionnaire 2A, 2B

These questionnaires are intended to be used for finding out the impact of more learning units (as a minimum, we recommend three units, however, it is possible to assign it after two units or one unit as well). As a “pre-test”, the tool will be assigned within two weeks before the first learning unit of the series, and as a “post-test”, it will be assigned within two weeks after the end of the last unit. It takes about 35 (for the lower level 25) minutes to complete this questionnaire.

Pilot study

Introduction

Item analysis and review were inspired by TIMSS 1999 Technical Report (2000). In order to assess the properties of the evaluation tools, several diagnostic statistics were computed. These statistics were carefully checked for any evidence of unusual item behavior. If an item had an untypical property, this sometimes
suggested a translation or printing problem. On the relatively few occasions that such items were found. Any item that was discovered to have a flaw in a particular type of the questionnaires (in a particular country), a special attention was paid to similar cases in other types of the questionnaires and their translations.

This review and item analysis consists of the following parts:

- sample
- time needed to complete the questionnaire
- omitted items
- consistency of results

The basic statistics for the item analysis were calculated using MS Excel and Statistica.

**Sample**

The sample of the participants included in the pilot study is shown in Table 1.

**Table 1.** Sample of participants

<table>
<thead>
<tr>
<th>Type of questionnaire</th>
<th>Czech Republic</th>
<th>Germany</th>
<th>Italy</th>
<th>Poland</th>
<th>Slovakia</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 A</td>
<td>136</td>
<td>54</td>
<td>15</td>
<td></td>
<td></td>
<td>205</td>
</tr>
<tr>
<td>1 B</td>
<td>26</td>
<td>64</td>
<td>31</td>
<td></td>
<td></td>
<td>121</td>
</tr>
<tr>
<td>2 A</td>
<td>22</td>
<td>54</td>
<td>13</td>
<td>199</td>
<td></td>
<td>288</td>
</tr>
<tr>
<td>2 B</td>
<td>26</td>
<td>64</td>
<td>57</td>
<td></td>
<td>199</td>
<td>147</td>
</tr>
<tr>
<td>Total</td>
<td>158</td>
<td>52</td>
<td>236</td>
<td>116</td>
<td>199</td>
<td>761</td>
</tr>
</tbody>
</table>

**Time needed to complete the questionnaire**

According to the obtained information, the estimated time to complete the questionnaires was not exceeded.

**Omitted items**

The percentage of students that omitted the item is less than 5 % (for a country and a type of the questionnaire). However, there are several exceptions.

**Consistency of results**

To determine the consistency of results, the Standard Pearson correlation coefficient was computed (available in Statistica). For this purpose, the data from the Czech Republic (1 A, N = 136) was used, because this sample is the largest one. In case of the Italian and Polish questionnaires 1A, there is a huge amount of missing data or data of poor quality.

**Table 2.** Subscale Interest / Enjoyment (Czech Republic, 1 A, N = 136)

<table>
<thead>
<tr>
<th></th>
<th>Item 3</th>
<th>Item 5</th>
<th>Item 7</th>
<th>Item 11</th>
<th>Item 12(R)</th>
<th>Item 15</th>
<th>Item 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 5</td>
<td>0.725</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 7</td>
<td>0.760</td>
<td>0.747</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 11</td>
<td>0.741</td>
<td>0.679</td>
<td>0.714</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 12(R)</td>
<td>-0.610</td>
<td>-0.575</td>
<td>-0.670</td>
<td>-0.640</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 15</td>
<td>0.681</td>
<td>0.626</td>
<td>0.678</td>
<td>0.722</td>
<td>-0.494</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 17</td>
<td>0.620</td>
<td>0.628</td>
<td>0.707</td>
<td>0.645</td>
<td>-0.598</td>
<td>0.635</td>
<td></td>
</tr>
<tr>
<td>Item 23</td>
<td>0.709</td>
<td>0.728</td>
<td>0.814</td>
<td>0.731</td>
<td>-0.662</td>
<td>0.692</td>
<td>0.684</td>
</tr>
</tbody>
</table>
Table 3. Subscale Perceived Choice (Czech Republic, 1 A, N = 136)

<table>
<thead>
<tr>
<th>Item 2</th>
<th>Item 8(R)</th>
<th>Item 9</th>
<th>Item 14(R)</th>
<th>Item 18(R)</th>
<th>Item 20(R)</th>
<th>Item 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 8(R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 9</td>
<td>0.458</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 14(R)</td>
<td>-0.452</td>
<td>0.639</td>
<td>-0.397</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 18(R)</td>
<td>-0.376</td>
<td>0.483</td>
<td>-0.318</td>
<td>0.649</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 20(R)</td>
<td>-0.472</td>
<td>0.615</td>
<td>-0.433</td>
<td>0.707</td>
<td>0.695</td>
<td></td>
</tr>
<tr>
<td>Item 22</td>
<td>0.429</td>
<td>-0.363</td>
<td>0.286</td>
<td>-0.443</td>
<td>-0.403</td>
<td>-0.408</td>
</tr>
<tr>
<td>Item 24(R)</td>
<td>-0.473</td>
<td>0.392</td>
<td>-0.484</td>
<td>0.489</td>
<td>0.414</td>
<td>0.511</td>
</tr>
</tbody>
</table>

Table 4. Subscale Value / Usefulness (Czech Republic, 1 A, N = 136)

<table>
<thead>
<tr>
<th>Item 1</th>
<th>Item 4</th>
<th>Item 6</th>
<th>Item 10</th>
<th>Item 13</th>
<th>Item 16</th>
<th>Item 19</th>
<th>Item 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 4</td>
<td>0.449</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 6</td>
<td>0.421</td>
<td>0.553</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 10</td>
<td>0.364</td>
<td>0.445</td>
<td>0.407</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 13</td>
<td>0.358</td>
<td>0.654</td>
<td>0.363</td>
<td>0.342</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 16</td>
<td>0.348</td>
<td>0.492</td>
<td>0.478</td>
<td>0.385</td>
<td>0.479</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 19</td>
<td>0.528</td>
<td>0.531</td>
<td>0.584</td>
<td>0.466</td>
<td>0.535</td>
<td>0.661</td>
<td></td>
</tr>
<tr>
<td>Item 21</td>
<td>0.406</td>
<td>0.652</td>
<td>0.642</td>
<td>0.355</td>
<td>0.657</td>
<td>0.570</td>
<td>0.608</td>
</tr>
<tr>
<td>Item 25</td>
<td>0.346</td>
<td>0.652</td>
<td>0.592</td>
<td>0.402</td>
<td>0.414</td>
<td>0.771</td>
<td>0.714</td>
</tr>
</tbody>
</table>

Based on the findings (Table 2, 3, and 4), we can conclude that participants’ answers are consistent (not responded mechanically).

Conclusion

For collecting evidence of the impact of ESTABLISH project on students, two questionnaires each in two versions have been developed. The particular parts of the questionnaires have been adapted from already existed tools, as it has been suggested in the project proposal. The choice of the relevant tools has been based above all on the objectives of the project impact assessment. In the case we could make a choice among more available tools we discuss motivation and criteria underlying the final choice. The relevance of the created tools has been proofed by the pilot study. The main changes proposed for the improvement of the questionnaire survey are the following: review of translation, attention to printing, and adding the participant’s birth date to the code in the header of the questionnaire. We can add to them that it is necessary to increase motivation of students (and teachers as well) to complete the questionnaires.
References


Website of ESTABLISH project [http://www.establish-fp7.eu/].
Physics Pedagogy and Assessment in Secondary Schools in The USA

Gordon P. Ramsey, Loyola University Chicago, Chicago, IL 60626
Melissa M. Nemeth, Loyola University Chicago, Chicago, IL 60626
David Haberkorn, Loyola University Chicago, Chicago, IL 60626

Abstract

The objective of this project is to compare the effectiveness of teaching styles used in high school physics classes and the methods used to assess them. We would like to determine those approaches to physics at the high schools that work and those that do not work for students from different demographics. We send out a survey to high school physics teachers in the U.S. Midwest states, inquiring about student preparation, pedagogy in the classroom, assessment and professional development. We found that there are differences in the practices of physics teachers in all of these areas, depending on the school location, be it rural, suburban or urban. Our results enable us to report on the most common successful practices in physics courses for these demographic areas.

Introduction

The motivation behind this study is a desire to improve physics education, especially at the secondary school level. We believe that science is an essential component of education for all, and one of the key purposes of science education should be to promote scientific literacy and appreciation.

Recent TIMMS\(^1\) and “Nation at Risk”\(^2\) reports from the U.S. government indicate that our high school science students are behind most of the industrialized countries in the world. This has been attributed to such factors as teachers that are ill prepared to teach in science subjects (particularly physics), outdated curriculum and teaching methods that are ineffective. The purpose of this project is to isolate one of these factors, namely teaching methods (which may be coupled to curriculum) to determine those that have proven most effective for different populations of high school physics students. Similarly, we would like to know if any methods were not effective and possibly isolate the reasons for their ineffectiveness. There exist studies of various teaching methods in secondary physics,\(^3,4,5\) but none address the students for which these methods appear to be the optimum. That is where this study is unique and of interest to a wide audience of high school physics teachers. The assessment methods will also be studied to determine how teachers determine the effectiveness of their methods.

As physics provides a crucial link between mathematics and science, high school physics teachers are under constant pressure to deliver the best education possible. Our research aims to uncover current best practices in secondary physics education and make recommendations based on our key findings. With the knowledge that students’ socioeconomic status and teachers’ experience affects the way physics is taught, we surveyed teachers in the categories of demographics, student and teacher backgrounds, teaching practices, and assessment techniques. Using current education research, we created a measuring tool to rank and quantify responses in these categories. We used these numbers to quantify the key findings presented. Our main objective is to make recommendations of specific ways to make high school physics more engaging with the ultimate goal of ensuring higher student success in college and beyond.

There are four major levels of education in the United States\(^6\): grammar school (K-5), middle school (6-8), high school (9-12) and college (13-16). Basic science education begins during the grammar school years. The divisions of biology, chemistry and physics are taught at the middle school level. Although science curriculum varies in different states, some programs integrate the sciences during the middle school years. The high schools have separate courses in biology, chemistry and physics, but ordering varies from state to state. Each state has their own science standards, but there are movements to introduce and test nationwide standards. Studies like this one may lend insight on how current practices can help meet and exceed the standards, regardless of the level at which they are imposed.
There are three major geographic distributions of school districts in the U.S.: rural, suburban and urban. Rural schools are prevalent in the largest geographical area of the U.S. They lie outside the larger cities and suburbs. On average, there are one to two high school physics teachers per district. Most schools are public with few private schools. The school sizes vary, but average about 700 students per school. Suburban schools are those that lie outside the limits of most larger cities and may encompass the counties surrounding the city itself. They consist of a mix of public and private schools. The student population averages about 1650 students per school with three to seven physics teachers per school. Urban schools are those within the city limits of cities with population of 100,000 or more. They also consist of a mix of public and private schools. Typically there are many schools within the geographic area, so there are fewer students per school at about 1400. Depending upon the city district, there are on average one to four physics teachers per school.

Typical science standards for secondary schools in the Midwest include the following elements:

- Applications for learning (inquiry)
- Formulate and solve problems (concepts)
- Interpret information and ideas (principles)
- Use appropriate instruments (design)
- Connect ideas among learning areas (STS)
- Common Core standards in science.

Accordingly, our survey asked questions on guided inquiry, pedagogy, technology, engaging curriculum, homework and group work, communication and assessment. We purposely did not ask specifically about teaching to standards, since the focus of our work is what actually takes place in and out of the classroom. This paper is a report of work in progress. It outlines the key results of our survey and summarizes the classroom practices that are typical in high school physics courses for rural, urban and suburban areas in the Midwest portion of the U.S.

Overview of research methods

A. Survey overview and key definitions

1. Overview of the Survey

Survey data was obtained from high school physics teachers in seven Midwest states. We asked what methods they have found to be effective. The effectiveness of these is substantiated by appropriate assessment (e.g., grades or standardized test scores). The data were compared with the demographics of their students, such as whether the school is located in a rural, suburban or urban area, as this is an important factor in their approach to teaching physics and their degree of success.

The survey consists of fifty questions, divided into six parts:

1. Demographics
2. Student Preparation
3. Pedagogy
4. Communications and other skills
5. Assessment
6. Professional Development.

The demographic information is used to determine backgrounds, experience that our respondents have and the location and type of school where they teach. These variables may help to distinguish if background and teaching experience are variables that affect the classroom and assessment practices in high school physics classes. Much of our analysis tries to distinguish practices for different bodies of students. Therefore, we divided the schools into five groups, separated by location (rural, suburban and urban) and type (public or private), since each cohort experiences different constraints and standard practices. The aim is to be able to make recommendations for each group, based upon their particular cohort of students.
It is well known from science education studies that students enter physics courses with conceptions that are not accepted by science, or "misconceptions". These are typically firmly embedded in their understanding of science and must be overcome for the students to have a fundamental understanding of physical concepts. The Student Preparation section of the survey attempts to determine the misconceptions that students of each cohort have when the enter a physics class. We follow up by asking what the teachers are doing to address these misconceptions.

The section on Pedagogy reflects one of the main focuses of the study. We ask about techniques used in the classroom, curriculum, technology and making the experience relevant to the students. This is the section that is most pertinent to the science standards listed in the last section. We correlated this with background, experience and other teaching practices for each respondent. The results of this analysis can be valuable for teachers to improve their effectiveness for each cohort of students. By comparing what others have been successful in implementing, it is hoped that teachers in a similar situation can improve their students’ experience in physics classes.

It is important to frequently communicate with students, particularly on their progress toward learning goals. Communications can serve two purposes: (i) to inform the student on how they can improve their performance and (ii) to inform the teacher about class weaknesses so that they can be properly addressed. Thus, we inquired about the methods and frequency of communication with students and how it affects teaching practices.

The Assessment section is the other main emphasis of our study. This determines how the teachers measure the effectiveness of the pedagogical approach that they outlined in the previous section of the survey. We asked about various methods used for assessment and how the information is used for determining effectiveness and adjusting classroom practices to achieve the course goals.

Finally, morale and school environment of a teacher are elements that can play a vital role in their effectiveness and motivation to continue teaching. We wanted to determine the extent of mentoring and collaboration for the teachers of each cohort to suggest ways that teachers can be more effective in a given learning environment. Both the presence of collaborators and involvement in professional organizations can contribute effectively to this motivation. We concluded the survey with related questions.

2. Introduction to Quantitative Analysis

In an effort to quantify the different aspects of classroom engagement level, we asked several questions about teachers’ curricula and classroom management. As detailed below, created a set of quantitative analysis numbers to describe engagement levels in different ways: the Nominal Response Number, the Engagement Number and the Curriculum Relevancy Number. Since assessment is an important aspect of determining the effectiveness of the pedagogy, we assigned an Assessment Number to each respondent. These numbers were based on research that shows the more different ways teachers engage and assess their students, the more the students will learn.

**Numerical Response Number (NR#)** The NR# is a weighted average of the percentage use of these 5 methods in the classroom: lecture, demonstration, discussion, problem solving, and laboratory, in order of student involvement with lecture being the least. The lecture is assigned a value of one and the laboratory five, with the others represented by the integers in between. To find the NR#, the decimal equivalent of the percentages of each method is multiplied by the integer and summed. Thus,

\[
NR# = \frac{\sum_{\text{methods}} \text{[percent of method use x (integer value of method)]}}{100}.
\]

The NR# has a range of from 1 to 5 and is a rough measure of the degree of student involvement in the classroom.

**Engagement Number (E#)** The E# is a sum of the number of engaging methods used from this list: labs, video, demonstration, group work, feedback systems, projects, online communities. The E# is an indication of the variety of engagement methods used in the classroom, without regard to weighting the effectiveness of each.
Assessment Number (A#) The A# is a sum of the number of formal assessment tools used from this list:

1. *Traditional*: tests, quizzes
2. *Portfolio*: journals, reflections, lab notebooks, projects, presentations, demonstrations, creative products.

The A# indicates the variety of assessments that the teacher uses as part of their courses.

Curriculum Relevancy Number (CR#) The CR# is a sum of the number of methods used to make the curriculum relevant to students' lives from the following: articles, practical experiments, live demonstrations, realistic physics problems, guest speakers, field trips, social networking). This is a measure of the teacher's efforts to bring practical applications to their curriculum.

Many of our findings were correlated with these numerical quantities. As there are many correlations in our analysis, we include only a subset of these to be reported here.

B. Demographics

The demographical information of teachers with valid responses is shown in Table 1, where we separate the categories by gender. This is to ensure that we have adequate diversity in the responses. The secondary school physics teaching experience categories are defined as "New" (1-3 years), "Intermediate" (4-6 years) and "Experienced" (more than six years). A majority of the respondents are experienced teachers, which gives us an indication of what teachers are doing that have possibly tried different approaches in and outside of the classroom. The relative numbers of public and private schools represented are consistent with the actual percentages for each of the three location categories. Table 2 shows the relative experience and physics background training for the three location categories. These are all consistent with each other, showing that we have targeted experienced teachers with background training equivalent to a major or very strong minor in physics.

We sent just over 1300 surveys by e-mail to high school teachers in seven Midwest states. After three months, we received 93 responses that completed the demographic data (a rate of 7.2%). A total of 79 completed the entire survey. All of these teachers were present or former members of the American Association of Physics Teachers (AAPT). We chose this cohort, since these would be teachers that are likely to employ a diversity of teaching techniques, involve the students in their own learning and be slightly more experienced in the high school physics classroom. We realize that this is not all-inclusive, but future work will include a much broader base of teachers. Table 1 gives a demographic distribution by gender, including new, intermediate and experienced teachers. Most of the teachers are experienced, as we expected from this cohort. A large majority is in public schools, since these are a major portion of rural and urban school systems. The "average" backgrounds of the respondents are shown in Table 2. The "semester hours of physics" category inquired about how much physics training the teacher had in college. Between ten and twenty would be considered a minor and more than twenty, a major in physics. The college training and teaching experience are consistent for all categories of schools, indicating a more homogeneous group.

<table>
<thead>
<tr>
<th>Gender</th>
<th>New</th>
<th>Intermediate</th>
<th>Experienced</th>
<th>Public</th>
<th>Private</th>
<th>Sem. Hr Phys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>1</td>
<td>2</td>
<td>22</td>
<td>18</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Male</td>
<td>3</td>
<td>10</td>
<td>58</td>
<td>53</td>
<td>11</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 1. Gender Distribution of Demographics in total numbers

<table>
<thead>
<tr>
<th>Category</th>
<th>Rural</th>
<th>Suburban</th>
<th>Urban</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number</td>
<td>24</td>
<td>48</td>
<td>22</td>
<td>92</td>
</tr>
<tr>
<td>Average years teaching</td>
<td>19</td>
<td>17</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Average sem. hrs. phys.</td>
<td>30</td>
<td>26</td>
<td>25</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 2. Backgrounds of Respondents
Key findings

A. Pedagogical Data

1. Preparation of entering Students

In science education research, it is accepted that students come to courses with conceptions that differ from scientists’ and must be addressed in instruction. These “misconceptions” (i) are strongly held; (ii) differ from expert conceptions; (iii) affect how students understand natural phenomena and scientific explanations; and (iv) must be overcome for students to achieve expert understanding. One of the initial concerns of a physics teacher is the background with which the students enter the course. We asked about the key misconceptions with which students typically enter the course and what the teachers do to bring their students to a satisfactory level for the course material. Table 3 indicates the areas in which misconceptions exist, separated by the three locations (rural, suburban and urban) and by public versus private schools. Lack of understanding physics concepts is the leading area for all categories. This may come from not having a prior course in physics. Physical science courses in middle schools often emphasize the biological sciences at the expense of the physical sciences. Weak math backgrounds are typical of about two-thirds of the students. This tends to be higher in private schools, although it is not clear why. The results in the other categories of units, nature of science and matter are dependent upon the location. Students in rural and urban schools typically do not have as strong backgrounds as more affluent suburban schools. The choices for methods to overcome this lack of preparation included science review, math review, embed misconceived topics into the course work, individual assistance, separate tutoring, adjusting the curriculum and adjusting the pace of the course).

Table 3. Types of Misconceptions/Weaknesses (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Units</th>
<th>Nature of Science</th>
<th>Math</th>
<th>Matter</th>
<th>Physics concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>39</td>
<td>65</td>
<td>65</td>
<td>57</td>
<td>96</td>
</tr>
<tr>
<td>Suburban</td>
<td>50</td>
<td>41</td>
<td>70</td>
<td>43</td>
<td>93</td>
</tr>
<tr>
<td>Urban</td>
<td>70</td>
<td>60</td>
<td>70</td>
<td>43</td>
<td>93</td>
</tr>
<tr>
<td>Public</td>
<td>46</td>
<td>51</td>
<td>68</td>
<td>51</td>
<td>94</td>
</tr>
<tr>
<td>Private</td>
<td>75</td>
<td>56</td>
<td>81</td>
<td>38</td>
<td>88</td>
</tr>
</tbody>
</table>

Table 4. Methods to overcome the lack of preparation (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Science review</th>
<th>Math review</th>
<th>Embed review</th>
<th>Individual Assistance</th>
<th>Tutor</th>
<th>Adjust curr.</th>
<th>Adjust Pace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>30</td>
<td>39</td>
<td>87</td>
<td>70</td>
<td>22</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>Suburban</td>
<td>25</td>
<td>20</td>
<td>84</td>
<td>73</td>
<td>27</td>
<td>50</td>
<td>34</td>
</tr>
<tr>
<td>Urban</td>
<td>15</td>
<td>35</td>
<td>80</td>
<td>65</td>
<td>15</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>Public</td>
<td>24</td>
<td>31</td>
<td>82</td>
<td>69</td>
<td>23</td>
<td>54</td>
<td>38</td>
</tr>
<tr>
<td>Private</td>
<td>25</td>
<td>19</td>
<td>94</td>
<td>75</td>
<td>25</td>
<td>44</td>
<td>6</td>
</tr>
</tbody>
</table>

The most common practices for those teachers that have the most interactive classrooms (indicated by the NR#) and most engaging classes (indicated by the E#) are embedded review, individual instruction (assistance) and adjusting the curriculum. These are shown in Table 5.

Table 5. Addressing misconceptions-top teachers’ practices

<table>
<thead>
<tr>
<th>Top respondents</th>
<th>Embedded Review</th>
<th>Individual instruction</th>
<th>Adjust curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR#≥2 (avg=1.94)</td>
<td>79</td>
<td>74</td>
<td>54</td>
</tr>
<tr>
<td>E#≥4 (avg=3.98)</td>
<td>86</td>
<td>73</td>
<td>57</td>
</tr>
</tbody>
</table>
2. Engaging and Relevant Curriculum

Studies have shown that students are more motivated and learn more when the curriculum is made engaging and relevant. There are various ways to accomplish the goal of making the classroom engaging, including but not limited to:

- computer simulations
- laboratory experience
- demonstrations
- group discussion and problem solving
- frequent feedback on work
- project work, and
- online resources.

We asked teachers about the ways that they make their classes more engaging. Table 6 indicates the percentages of respondents that use these techniques in their classes. Laboratories and demonstrations are by far the most frequently used in all locations. This is followed by group work and computer simulations. Rural schools have access to computers, but not as much demonstration equipment available. This may explain the difference in those columns for these schools. Since we did not ask about the amount of labs that were performed, it is not clear from the survey results how diverse the lab equipment is typically available to the rural schools. The average engagement number for the cohort was about 4.4, indicating the number of ways that teachers make the classroom engaging.

Table 6. Ways to make curriculum engaging (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Sims</th>
<th>Labs</th>
<th>Demos</th>
<th>Groups</th>
<th>Feedback</th>
<th>Projects</th>
<th>Web</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>63</td>
<td>92</td>
<td>63</td>
<td>67</td>
<td>17</td>
<td>42</td>
<td>8</td>
</tr>
<tr>
<td>Suburban</td>
<td>39</td>
<td>85</td>
<td>67</td>
<td>72</td>
<td>28</td>
<td>24</td>
<td>7</td>
</tr>
<tr>
<td>Urban</td>
<td>41</td>
<td>82</td>
<td>77</td>
<td>68</td>
<td>14</td>
<td>41</td>
<td>14</td>
</tr>
<tr>
<td>Public</td>
<td>47</td>
<td>87</td>
<td>68</td>
<td>69</td>
<td>21</td>
<td>32</td>
<td>14</td>
</tr>
<tr>
<td>Private</td>
<td>44</td>
<td>81</td>
<td>75</td>
<td>75</td>
<td>31</td>
<td>38</td>
<td>6</td>
</tr>
</tbody>
</table>

A Scientific American feature article by Gibbs and Fox states “the false crisis in science education masks the sad truth that the vast majority of students are taught science that is utterly irrelevant to their lives”. In addition to making the classroom engaging, it is important to attach relevance to the physics topics. Teachers can make the material relevant to their students’ lives in a number of ways, including:

- articles relating to the physics topic
- association to life experiences
- demonstrations with simulations and modeling
- experiential examples with realistic numerical values
- guest speakers
- field trips, and
- online resources.

Table 7 indicates the percentage of respondents that use each of these methods to make the material relevant. The most prevalent methods include life experiences and related numerical examples. Demonstrations are used extensively, except in rural areas where less equipment is typically available. Articles and online resources are used by about one half of the cohort. Speakers and trips are less used.
due to the time and monetary costs of these methods. It is apparent that more connections of physics topics to the "real world" are more effective in making physics relevant to students’ experiences. This is not surprising, but confirms our expectations with actual data.

Table 7. Making curriculum relevant (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Articles</th>
<th>Life Exp</th>
<th>Demo</th>
<th>Example</th>
<th>Speakers</th>
<th>Trips</th>
<th>Web</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>46</td>
<td>75</td>
<td>46</td>
<td>71</td>
<td>21</td>
<td>25</td>
<td>63</td>
</tr>
<tr>
<td>Suburban</td>
<td>43</td>
<td>74</td>
<td>68</td>
<td>72</td>
<td>13</td>
<td>38</td>
<td>49</td>
</tr>
<tr>
<td>Urban</td>
<td>55</td>
<td>86</td>
<td>77</td>
<td>64</td>
<td>9</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>Public</td>
<td>45</td>
<td>77</td>
<td>62</td>
<td>71</td>
<td>13</td>
<td>35</td>
<td>49</td>
</tr>
<tr>
<td>Private</td>
<td>50</td>
<td>81</td>
<td>75</td>
<td>63</td>
<td>19</td>
<td>25</td>
<td>63</td>
</tr>
</tbody>
</table>

3. Role of Technology in the Classroom

In the past three decades, the role of technology in the classroom has greatly evolved. In many classrooms, technology plays a primary role in learning physics. We asked the teachers about their use of PowerPoint presentation, simulations, Web resources, clickers, Web projects, video analysis and lab interfacing equipment. Table 8 indicates the percent of respondents that use these tools in their classes. We found that teachers in our survey were more likely to use technology in the classroom if one or more of the following is true:

- the more semester hours of physics they had taken in college
- the higher their Engagement Number (E#)
- the more ways they check for their effectiveness (A#)
- the higher their Curriculum Relevancy Number (CR#).

Rural suburban and urban schools all showed similar use of technology in the classroom, showing that types of schools generally have equal access to technological resources.

Table 8. Use of technology (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>PPT</th>
<th>Sims</th>
<th>Web</th>
<th>Clickers</th>
<th>Web project</th>
<th>Video</th>
<th>Lab eqmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>42</td>
<td>71</td>
<td>33</td>
<td>8</td>
<td>4</td>
<td>46</td>
<td>75</td>
</tr>
<tr>
<td>Suburban</td>
<td>45</td>
<td>62</td>
<td>36</td>
<td>21</td>
<td>6</td>
<td>49</td>
<td>77</td>
</tr>
<tr>
<td>Urban</td>
<td>36</td>
<td>73</td>
<td>36</td>
<td>5</td>
<td>9</td>
<td>45</td>
<td>68</td>
</tr>
<tr>
<td>Public</td>
<td>44</td>
<td>65</td>
<td>32</td>
<td>13</td>
<td>6</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>Private</td>
<td>31</td>
<td>75</td>
<td>50</td>
<td>19</td>
<td>6</td>
<td>56</td>
<td>69</td>
</tr>
</tbody>
</table>

The top four uses: are lab interface equipment, computer simulations, video analysis of phenomena and PowerPoint presentations. There is a significant increase in technology use for experienced versus new or intermediate teachers.

4. Improving Courses

In light of all the pedagogical information, we wanted to determine what factors the teachers considered important in improving their courses. The gives an indication of those elements that are not as strong as the teachers would like for their courses. The choices include: smaller classes, more lab equipment, larger budget, course development time and more technology. The results are shown in Table 9. The most desired element across the board was more time to further develop their courses. Suburban schools tend to have large class sizes due to the numbers of students in the school that take physics (usually a larger percentage in the suburbs), so smaller class size was important in those schools. Lab equipment is more in need at the rural schools due to smaller budgets per school.
Table 9. Improving courses (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Smaller class</th>
<th>Lab eqmt</th>
<th>Budget</th>
<th>Devt time</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>13</td>
<td>46</td>
<td>38</td>
<td>79</td>
<td>38</td>
</tr>
<tr>
<td>Suburban</td>
<td>53</td>
<td>23</td>
<td>28</td>
<td>51</td>
<td>17</td>
</tr>
<tr>
<td>Urban</td>
<td>36</td>
<td>18</td>
<td>23</td>
<td>55</td>
<td>9</td>
</tr>
<tr>
<td>Public</td>
<td>40</td>
<td>29</td>
<td>30</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td>Private</td>
<td>31</td>
<td>25</td>
<td>25</td>
<td>44</td>
<td>0</td>
</tr>
</tbody>
</table>

B. Assessment

Assessment serves the purpose of learning and is consistent with and complementary to good teaching. Teachers use a variety of assessment procedures to recognize where students are located in their development and plan learning experiences that move students toward desired learning outcomes. We surveyed teachers on multiple aspects of their assessment practices to uncover the most common approaches to student evaluation and its purpose in the average high school physics teacher’s classroom. In our study, teachers who gave more types of assessments received higher Assessment numbers. We then compared the teachers with the highest numbers to the average survey data to make recommendations.

Various assessment tools can be used to recognize students’ progress. Tests fall into various categories, including unit level, cumulative tests incorporating many units and standardized tests, which tend to be more comprehensive. Grades are also based upon many units and cover a larger time period than unit tests. Tests fall into various categories, including unit level, cumulative tests incorporating many units and standardized tests, which tend to be more comprehensive. Grades are also based upon many units and cover a larger time period than unit tests. Homework gives periodic feedback on how students are understanding the material. Projects tend to occur at the end of a series of units or the end of a course, where many concepts are combined to carry out the project. Private conversations with students tend to be a shorter-range feedback mechanism and are designed to help individual students, especially those that have more trouble with understanding. Corresponding with the assessment tools, the most popular feedback methods to follow up the assessment are written notes (for labs and homework), verbal discussion and forms of technology such as conversations or remedial tutorials. Table 10 shows the percent of respondents that use these tools for assessment.

Table 10. Assessing effectiveness (percent of respondents)

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Grades</th>
<th>Std tests</th>
<th>Unit tests</th>
<th>Projects</th>
<th>Cum tests</th>
<th>HW</th>
<th>Converse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>46</td>
<td>8</td>
<td>92</td>
<td>25</td>
<td>38</td>
<td>54</td>
<td>71</td>
</tr>
<tr>
<td>Suburban</td>
<td>51</td>
<td>40</td>
<td>85</td>
<td>26</td>
<td>49</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td>Urban</td>
<td>55</td>
<td>41</td>
<td>82</td>
<td>36</td>
<td>41</td>
<td>59</td>
<td>68</td>
</tr>
<tr>
<td>Public</td>
<td>48</td>
<td>29</td>
<td>87</td>
<td>27</td>
<td>42</td>
<td>60</td>
<td>74</td>
</tr>
<tr>
<td>Private</td>
<td>63</td>
<td>50</td>
<td>81</td>
<td>31</td>
<td>56</td>
<td>75</td>
<td>56</td>
</tr>
</tbody>
</table>

In the verbal part of the survey, we asked how feedback from assessment is used to adjust elements of the course. Most teachers said they gave assessments to assess what the students know about the content. Twenty-five percent said they used their teaching/learning environment to help students take responsibility for their own learning. When asked what ways teachers use their assessments to adjust, most teachers in urban areas responded that they adjust their curriculum. Most rural teachers reported that they then re-teach the topic with the assessment results in mind (this was the second most popular option for urban and suburban teachers). Most suburban areas adjusted their teaching style. No urban teachers reported that they used assessments to adjust for the future.

Discussion and Recommendations

Our survey reflects the self-reporting of how high school physics teachers structure their classes to achieve the best results. The average data indicate what most teachers feel are best practices in their courses. It is clear that these more experienced teachers reflect on their teaching practices and the effectiveness...
of their courses. This validates the structure and content of the survey and our approach to extract appropriate information about common teaching practices and effectiveness.

Although students in the three demographic regions enter courses with different misconceptions, the most popular methods used to overcome these weaknesses are fairly common across the board. This indicates that these general approaches seem to work. See Tables 3-5. It is important to make the curriculum both engaging and relevant to students’ experiences. There are differences in the emphases on these techniques, depending upon the location, but the most common (labs demonstrations and group work for engagement and examples for relevance) are comparable for all areas. Refer to Tables 6-7. The use of technology is similar for all teachers, since most have access to some degree of equipment (Table 8). However, there are significant differences in rural versus suburban and urban desires for improvement of the courses (Table 9). Unit tests, homework and conversations were the most popular techniques to assess student progress (Table 10).

It is clear from these results that schools in rural, suburban and urban areas have somewhat different approaches to pedagogy, depending upon the background of their students and the resources that they have available. This leads to teachers in these areas having different needs to improve their approaches to the subject.

We have presented a brief summary of a larger body of work in progress to determine common practices in rural, suburban and urban high school physics courses. Our future plans consist of expanding the survey to a larger sample of teachers, outside the Midwest to encompass the geographical areas of the northeast, east, south and west parts of the U.S. This will also include non-AAPT members in public and private schools). This will allow us to expand the analysis for a larger sample and perform a study of differences in practices for these demographic areas. The recommendations we make will be based upon a wider spectrum of results, which could be valuable on a wide scale and of use to many more high school physics teachers.

**Acknowledgement**

We thank those who anonymously took the time to fill out our survey and those who gave us feedback to improve the format and content.

**Bibliography**


Changing Students’ Alternative Conceptions in Physics: An Example of Active Learning of Geometrical Optics at University Level

Zalkida Hadzibegovic, Faculty of Science, University of Sarajevo, Bosnia and Herzegovina
Josip Slisko Benemerita, Universidad Autonoma de Puebla, Mexico
Corresponding author e-mail: zalkidah@yahoo.com

Abstract

Problem of active involvement of students in physics learning, especially of those attending the physics lectures within high-enrollment courses, is not solved in traditional instructions and effective model of teaching and learning physics has not yet been provided. Students need personal and collaborative activities in the physics learning processes. Learning outcomes in geometrical optics of 95 students were investigated. Around 60% of them have changed their alternative conceptions of vision and image formation by observing and thinking about simple experiments on light reflection and refraction. In this way, students participated in an active learning sequence to better understand optics phenomena which they had never understood before. In this paper significant role of the experiments that should play in students’ learning sequence for changing their alternative conceptions in physics is presented. Actively involved students gave their justified predictions and argumentations before and after observation the experiments. Research findings show that traditional teaching/learning strategies should be changed. Main issue was the need for active involvement in the learning process instead of being obliged to a predominantly passive role during teacher’s talk-based lectures.

Keywords: active learning physics, changing alternative conceptions, in-class experiment, large enrollment, university physics education

Changing Students’ Alternative Conceptions in Physics: an Example of Active Learning of Geometrical Optics at University Level

Introduction

In general, students’ understanding and perception of physics learning has two sides. Initially, there is the gap between subject matters taught by teachers and learned by students (McDermott, 1991; McDermott, 1993; Heron & McDermott, 1998). Secondly, there are difficulties for students to develop concepts in physics (Dykstra et al., 1992; Posner et al., 1982). Main difficulties appear in practice, especially in problems solving procedures which must be based on good subject matter understanding. Several systematic investigations in the field of Physics Education Research (PER) have showed students’ difficulties to achieve a conceptual knowledge progress for better physics understanding and methodological plans used for helping students to reach better learning outcomes (Dedes & Ravanis, 2009; Deslauriers & Wieman, 2011; Milner-Bolotin et al., 2011). Research findings show that many different successful strategies and methods are helpful in solving some problems of conceptual understanding in physics. Traditional instructions, as only source for legitimate knowledge with students as passive learners, have to be changed into instructions with actively involved students and better utilization of teaching resources.

Active learning is individual and also group participation. Students are the key actors in the learning process, whereas the role of the instructor is to be a facilitator of this process. Active-learning physics methods in a large-class enrollment are in the main focus to comprise the effective activities such as: in-class observing, writing, experimenting, discussing, solving problems, talking about learned topics (DeBard & Guidera, 2000; Niemi, 2002). Some instructors found active learning environment as impossible, or, at least, difficult to be implemented in a large lecture session. Nevertheless, there is experimental evidence, the most impressive in SCALE-UP learning environment (Beichner, et al., 2000), that such beliefs are false. Meltzer and Thornton in a Resource Letter highlighted the role of active-learning methods in physics that
involves students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time, giving the evidences based on the PER results (Meltzer & Thornton, 2012).

In this study one possible design of active learning environment is presented. It is based on following elements:

(i) helping student to learn from interactive lecture experiment;

(ii) guiding student to use justified explanation and prediction after observing and exploring experiment;

(iii) developing a conceptual question sequence designed for use in interactive lecture with a student response system by in-class worksheet writing and discussion;

(iv) evaluating a student’s conceptual change and gain by exam question responses in a week after the active learning session.

Two research questions open a problem of large-class effective instructions within traditional model of teaching/learning physics.

RQ1: **How can university students be more actively involved in physics learning if they attend physics lectures within a large group placed in the amphitheater as their learning environment?**

RQ2: **How can active learning geometrical optics help students to improve their understanding of the phenomena in optics?**

Assessment of students’ understanding of geometrical optics about light reflection, light refraction and image formation was collected through their responses based on in-class observing and experiments in geometrical optics. It was carried out as in-class experiment, and worksheet writings, in-class discussions, as well as the mid-term exam questioning.

**Method**

This research study took place in Bosnia and Herzegovina, at Sarajevo University, in the spring semester 2011 for science major freshmen.

**Participants**

Data was collected from 95 freshmen (12% of males and 88% of females) who were enrolled in the science study at University of Sarajevo. They started in the university education with different secondary school backgrounds in physics. Around half of enrolled freshmen (52%) had previously finished high school (gymnasium) where they learned physics only two years in the first and second grade. Other students have studied physics in different high schools (mostly secondary medical school, and classic high school) for four years (41%), for only one year (5%), and there were a group of students who have never studied secondary school physics (2%). The students took part in this research that explored their conceptual knowledge in geometrical optics within a general physics course in the first year of study.

They were taught some topics of geometrical optics within 2-4 hours of General Physics course in the spring semester. Basic knowledge in geometrical optics was delivered to them in the last grade of elementary school (the eighth grade as the final grade). Through their regular general physics class in the spring semester 2011, science freshmen were taught some themes in geometrical optics, including the derivation of laws of geometrical optics based on mathematics knowledge at higher level compared with those in the secondary schools. However, students under research attended the traditional teaching physics classes in an amphitheater as only possible learning environment for such large group of students (Figure 1).
Based on the instructor’s experiences and by the statements of students themselves, it was evident that traditional teaching-learning method was inefficient and sometimes tiresome and monotonous. On the other hand, there were traditionally poor students’ achievements of the midterm exams that did not meet the goals for both students and their instructor. These reasons motivated their instructor (Z.H.) to explore opportunities to increase not only the students’ interest for deeper learning geometrical optics but to increase the number of students both for better understanding of the taught physics subject matter and to achieve a greater number of students passing exams.

One sequence of geometrical optics active learning was chosen as an activity in duration of 90 minutes. Results showed that before this change in teaching-learning physics introduced, around 90% of students after learning the same topics in geometrical optics at elementary school, high school and university level did not develop adequate basic concepts of the image formation of object if light reflects and refracts passing through different optical medium. In the chosen learning sequence (ALS) students were motivated to explore the basic concepts of image formations what they have never understood enough before. In their responses they should evaluate their predictions in a live experiment as an important step for personal evaluation of own learning geometrical optics and constructing a new meanings.

**Active learning sequence design**

Students were attended the instructor’s lecture on geometrical optics in the traditional way of teaching. ALS was implemented in three steps: first by the learning activities to observe an experiment with a metal sphere (MS) placed in bowl filled with air and water, second, in-class discussion after the ALS evaluation and the final step for answering the mid-term exam question related to all of preceding learning steps. Metal sphere was illuminated by daylight, and as a weighty body was located at the bottom of an opaque plastic bowl (Figure 2). One can notice that ALS implemented in this study is a version of very known experiment with a coin in the bowl, with and without water, seen in many physics textbooks. For this research, a big MS was more suitable than a small coin.

**Figure 2.** The experiment setting up in its three representations.
Notes. a) a plastics bowl, bottle of water and MS as needed materials for experiments; b) MS at the bowl bottom invisible from a chosen observer’s position; c) MS at the same place and same observer’s position but visible one.

In the first part of the experiment, students had a task to describe an image of the metal sphere verbally and in visual form (drawing) if the bowl was filled with air. In the second part of the experiment the POE (Predict-Observe-Explain) teaching technique was implemented. Students were required to present their responses in both parts of the experiment by in-class worksheet writings. Each of students was asked to perform the experiment in its both parts. All three phases of setting up the experiment are shown in Figure 2.

A worksheet, created and applied in the ALS, consists of three main activities by the POE protocol. The worksheet questions were addressing students’ conceptual understanding of light source role, the role of observer’s eye, light reflecting from the metal sphere, light refracting in the air-water and water-air systems, image formation and image nature.

Students’ responses about vision model (VM) were considered according to the created coding scheme, recognizing five presented students’ vision model and seven types of responses coded as:

SVM: scientific vision model (light rays travel from a light source to the MS as an subject of vision, its reflection or refraction-reflection-refraction and after light rays travel into observer’s eyes),

AVM1: alternative vision model 1 (light rays travel from the observer’s eyes to the MS);

AVM2: alternative vision model 2 (light rays travel from the MS into the observer’s eyes);

AVM3: alternative vision model 3 (light rays travel from a light source to the MS);

DVM: combining two models of vision among three models coded as alternative vision models.

NCV: without the concept of vision (nonphysical approach or an art work);

NR: no student’s response.

Both qualitative and quantitative data analysis is applied. In the focus of qualitative data analysis were students’ drawings in the frame of models of vision used. The quantitative analysis of students’ worksheet responses was implemented using scoring system related to the first and second part of worksheet activities, presented in Table 1 and Table 2.

Table 1.
ALS Worksheet I part content and grading score

<table>
<thead>
<tr>
<th>ALS – I part</th>
<th>Accepted answers</th>
<th>Grading points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prediction 1:</strong></td>
<td>Scientific vision model used:</td>
<td>1</td>
</tr>
<tr>
<td>Based on the Ray Model of Light predict the positions that you can see the metal sphere located at the bottom of an opaque bowl, filled with air. Mark the position of the eye of an observer in a point P (or sketch the eye in a proper position).</td>
<td>Drawing 1 is a set of two light rays at least that travel from a light source to the metal sphere reflect on it and reach the observer’s eye or position P.</td>
<td></td>
</tr>
<tr>
<td><strong>Observing 1:</strong></td>
<td>Student confirm the own prediction and own result of observing results.</td>
<td>1</td>
</tr>
<tr>
<td>student observes the metal sphere in the bowl and tries to evaluate own prediction. Student is asked to confirm her/his prediction with observing results.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Explanation 1:</strong></td>
<td>Using the scientific model of explanation for a new and correct drawing.</td>
<td>1</td>
</tr>
<tr>
<td>If there is a difference between the predicted and observed position of observer’s eye you need to make a better distribution of eye position that MS is visible. Use the Ray Model of Light.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Total number of worksheet grading points is six (6) points. The statistical data based on the results of the 95 students who responded to the worksheet questions in both the first and second part of the Worksheet activities were analyzed.

The third part of Worksheet consists of an open-ended question about students’ emotions and opinions and ALS experiences.

**Table 2.**

*ALS Worksheet II part content and grading score*

<table>
<thead>
<tr>
<th>ALS -II part</th>
<th>Activity</th>
<th>Accepted answers</th>
<th>Grading points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prediction 2:</strong></td>
<td>Correct answer is (d)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Metal sphere (MS) is at the same place in the bowl. If the bowl is filled with water predict what will happen if you observe the MS from the previous place of the invisible MS for you:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) The MS will be invisible</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) The MS visible part will be lower than in the air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) The MS visible part will be the same as in the air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(d) The MS visible part will be higher than in the air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e) It is not possible to predict the effect for MS visibility placed in the filled by water bowl.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Scientific vision model used:**

Drawing 2 is presented by at least two light rays that travel from the light source to the water surface and refracts in water changing the path. After reaching the MS the light rays are reflected on the metal sphere and then is refracted again leaving water and travel to the observer’s eye position P.

A seen MS is not its real image (new image is a case of the MS lifted in comparison of its previous positions in the bowl).

**Observing 2:** Perform the experiment.

Question 1: If your prediction 2 was correct you need to mark which one:

(a) (b) (c) (d) (e)

Question 2: If your prediction 2 was wrong you need to mark which one:

(a) (b) (c) (d) (e)
This study has focused on the conceptual knowledge in geometrical optics for a science freshmen group during and after ALS. The evaluation of students’ conceptual knowledge of geometrical optics after ALS was exam question in the mid-term exam.

Results and Discussions

Responses to the First and Second Part of the Worksheet Writings and Drawings

Students gave their responses related to the VM presented in the first part of Worksheet. Figure 3 shows mainly five different VM and other three categories of responses in the same task dimension.

Figure 3. The percentage distribution of the vision models used in the first part of the Worksheet responses. Most of students do not have their concept of vision scientifically developed. Only 7.2% of students presented their responses verbally or as drawings according to the SVM with three subjects of vision: a light sources, a body as subject of reflecting/refracting light, and eye for seen image of body. After instructor’s lecture in traditional manner of teaching and ALS realizing 73.2 % of students explored a vision model with only two subjects (an eye as a light source and the light entered into metal sphere). In such way they showed a long spectrum of their misconceptions without the basic concepts understanding of vision and Ray Model of Light.
Figure 4. Some copies of students’ drawings of five Models of Vision used by Ray Model of Light applied.

Notes. a) SVM presented in the drawing of the light reflection phenomenon with MS in air.; b) SVM presented in the drawing of the light refraction-reflection-reflection phenomena with MS in the bowl water filled; c) Two drawings presented application of the AVM1; d) A drawing presented application of the AVM2; e) A drawing presented application of the AVM3; f) A drawing presented the NCV; g) A drawing presented the DVM.

A huge group of students (27.3 %) did not apply any vision model, although they studied geometrical optics at three levels of physics education. Several drawings are shown in Figure 4 by instructor selection but as drawings correspond to the VM used during the first part of the worksheet activities. Chosen drawings were selected to present the students’ alternative VM conceptions.

Beside all instructions given during traditional lecture and ALS students did not use two rays of light entering in the observers’ eye for visual presentation their understanding of image formation by refraction and reflection of light (Figure 4, c-f).

Since the distribution of points related to the coding scheme presented above was not normal, the scores were expressed by median value of 2 points (Table 3).

Table 3
The students’ point distribution related to the scoring scheme given above.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of students (N=95)</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 points</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5 points</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3 points</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>2 points</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>1 point</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>0 points</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 also shows that the difference between the maximum and minimum number of points is 6 points. Especially important to note is the fact of very low number of students (<20%) who gave their explanations for each of the responses in the first and second part of the Worksheet. The situation is much better in the case of distribution of responses related to the predictions (Table 4).

Most of the students realized their first and second task of prediction, but it was accurate for around 60% of students in both type of ALS prediction phase (see Table 4).
Table 4.
The students’ percentage distribution by number of correct predictions, explanations and image formation

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of correct predictions (%)</th>
<th>Number of correct explanations (%)</th>
<th>Correct image formation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction 1</td>
<td>62</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>Prediction 2</td>
<td>63</td>
<td>11</td>
<td>0</td>
</tr>
</tbody>
</table>

Students’ worksheet writings showed lack of developed conceptual understanding of geometrical optics. Only two students presented the MS seen in water as an imaginary MS closer to the water surface. In the same time only five students used two rays of light entering in the observer’s eye. Looking at their textbooks previously used there are the correct figures showing two rays of light as a minimum number of rays entering into an eye.

Responses to the Third Part of Worksheet Open-Ended Question

The students had the opportunity to explore their emotions and thoughts about ALS realized in the amphitheater as their learning environment. Their comments are collected and divided into two groups: a group of satisfied students (93 students), and a group of students without expressed emotions (2 students). The highest positive standard of students’ responses frequencies follows:

The sequence of active learning geometrical optics in the way was realized is interesting and I like this way of teaching and learning (69% of students).

Active learning is useful, interesting and helps me to better understand and learn about the phenomena of the light reflection and light refraction (63% of students).

I really enjoyed this class (65% of students).

Carrying out the experiments, predictions and observations helps me to better understand physics as a very difficult subject matter for me (21% of students).

I have learned to use this technique of learning optics in my other classes which has helped me greatly because I learned and understood not recall and memorize (18%).

I learn better when I can see outcomes of the experiments. I cannot learn by heart the definitions and mathematics in the physical laws if I often do not understand them (6%).

This experiment of optics I have never forgot. I like very much this kind of activity in the classroom at all (6% of students).

For this method of learning I am definitely more interested than traditional teaching (5% of students).

I was effectively able to piece together the difficult problem of image formation through our active learning (2% of students).

Exam results related to the ALS understanding and learning

During their current semester students solved a midterm exam question that covers the ALS content. Number of points for correct answer of exam question was also six (6) points. Their ALS gained knowledge enabled them to achieve much better results then within the ALS activities. A possible reason is an in-class discussion organized by their instructor, and after received scores in the ALS. Among 130 students who were taking midterm exam there were 72% of students who earned between 4 and 6 points. Better conceptual understanding of the light refection on the opaque body, light refraction passing through different optical materials and image formation showed mostly students who participated in the ALS. Many of them completely changed their alternative conceptions showing understanding that they could not reach during traditional teaching lectures. Around 65% of students, who were actively involved in the ALS, successfully solved the exam problem. Some of students repeated wrong answers showing the
insufficiently understanding how an image character is, and how it is formed if light reflects or refracts passing two different optical media. Among 27% of students who did not be included in all of ALS activities before the examination there were 90% who did not earn any points from the scoring scheme.

Conclusion

This pilot study shows positive results as case of only one ALS applied in the General Physics lectures in duration of 90 minute. It was a way for involving a group of students with weak prior geometrical optics knowledge and lack of practice in active learning physics at university level. In the same time, it was a challenge for both students and instructor. Students under this or similar research need to be moved beyond memorization to higher levels of understanding.

The ALS, chosen for helping students to be more knowledgeable in geometrical optics, brought a change for both students and instructor. Even better change in the traditional lectures could be ALS organized as the team learning sequences for giving the opportunities to the students to discuss, to ideas confrontation, solutions and explanations by arguments, and collaboration in a student-student or in an instructor-student connection lines (Hernandez, 2002). Reported change for instructor has been a way to break up the traditional in-class teaching lecture with students’ active role to bring them in much more effective way of learning, communicating, and conceptual knowledge development. It was the opportunity to prepare students for higher level of subject matter understanding, and to achieve competency that are expected for students involved in science education and their future professional work.

The answer to the RQ1 is an affirmative belief of many possibilities to perform teaching-learning physics at university level, even in a large group of students and its inadequate learning environment. Very good exam results achieved by group of ALS practitioners are found as strong students’ benefits to confirm their success at the midterm exam. According to the RQ2, students confirmed their ability for better understanding themes of geometrical optics showed in the exam results. The confirmatory findings of better conceptual knowledge developed in the ALS have the evidences for around 65 % of students have solved the exam question correctly. All of 98% of students’ statements given in the third part of worksheet showed their affirmative attitudes to the active learning techniques for gaining students’ development for higher levels of thinking and creating at the top of the Bloom’s new taxonomy version (Krathwohl, 2002).

Some selected results described in this paper, concerning student responses to active-learning geometrical optics in a large-class enrollment, can be best characterized as exploratory findings. What more is needed for an experimental research that compares the effectiveness of active-learning environments to traditional learning environment? A simple answer goes to the benefits of using different and modern resources and technology (real-time computerized data collection and display, interactive computer simulations, live and virtual experiments, team learning, etc.). An active role of students is the only way for stronger stimulating their thinking and understanding which are needed in the application, analysis, evaluation and creation of knowledge as the most important objectives along cognitive process dimension.

References


Helping Primary School Teacher Students to gain insight in the requirements of science teaching

Ulrike Böhm, Center for Teacher Education and Research, Technische Universität Dresden, Germany, Ulrike.Boehm@mailbox.tu-dresden.de
Susanne Narciss, Department of Psychology, Technische Universität Dresden, Germany
Gesche Pospiech, Department of Physics, Technische Universität Dresden, Germany

Abstract

Science education is considered very important in a high tech world, yet, most students do not like science lessons very much. Synchronously to the beginning of science lessons in secondary school the interests and motivation of most learners are decreasing (Rheinberg & Wendland, 2002). Thus a lot of students – especially in the group of primary school teacher students – are not interested in science. In general, primary teacher education students are rather interested in working with little children than attracted by science issues and science teaching. But, these primary school teachers are the first teachers interacting with young children and teaching the ‘first steps in science’. In doing so, the often rely on special science offers for children on TV, on the Internet or in newspapers. But what about the quality of these special offers – do they foster a deep understanding of science or do they rather create confusion and/or illusions of knowing? The purpose of this paper is to address this issue by investigating the following questions: (1) How can the science education and teaching framework of “Multiperspective Modelling” (Böhm, 2012) be applied to help primary education students to gain insight in the requirements of explaining scientific experiments? and (2) What effects has a special science teaching course using this framework on primary education students’ motivation and conceptions of science teaching. First, this paper describes the theoretical framework ‘Multiperspective Modelling’ (Böhm, 2012), which provides a theoretical basis for science education and teaching. Second, we illustrate how this framework can be use for analyzing special science experiments primary teachers consider as exciting experiments for children (e.g., the “Raisin Lift”-experiment). Third, we outline how such experiments have been analyzed according to the framework in a special science teaching course for primary school teacher students. In order to evaluate the effects of this course we used a mixed-method approach including the assessment of students’ motivation prior to and after the course, as well as students’ reflections and feedback, and the teacher’s observations and feedback. The findings of this evaluation study indicate that the course contributed to a better understanding of the requirements of science teaching. However, this better understanding elicited the challenges of science teaching, and was related to a decrease in students’ motivation. Implications of these findings for teacher education programs are discussed.

Introduction

Science lessons are not very popular in school. Synchronously to the beginning of science lessons in secondary school the interests and motivation of most learners are decreasing (Rheinberg & Wendland, 2002). In particular, many primary education students are not interested in science. In general, these students are interested in working with little children and not mainly attracted by the subjects they teach. Thus, they don’t consider science and science teaching as very important during their studies. But, primary education teachers are the first teachers interacting with young children and they have to design instructional settings in which children learn about science.

On the other hand science is very popular in this day and age – we have science TV for children, ‘House of the little researchers’ (http://www.haus-der-kleinen-forscher.de, 28.10.12), projects for science teaching in kindergarten and primary school. There is a huge amount of books and Internet sites with little experiments for children. Often these experiments are not described by scientists, but rather by certain people with different backgrounds (e.g. kindergarten teachers, children’s book writers). Mostly these are ‘exciting’ experiments like the “Raisin Lift” described below. Another famous experiment is the “Potato Battery”, where children can build a current circuit with potato, cupric and zinc spikes, cable and...
earphones. The children have to put the things together and when they put on the headset, they can hear a sizzling noise. What is it? - It is electricity. Ramseger (2010) criticized the learning experience (children have to learn where the current comes from) in this experiment. Prior to that experiment they believed that it comes from the electrical socket, now they learned that it comes from the potato – they only have to put the plug in it. Both conclusions are nonsense.

Based on these facts two questions arise: (1) How can we help primary school teacher students to gain insight in the requirements of science teaching? and (2) Which principles should they respect when they are teaching science to little children?

To answer the first question we have to think about the development of understanding physics and also about the epistemology of physics. At first we have to consider the gap between the observed reality and the reality modelled in physics lessons. Normally we do not discuss the fact in science lessons that we are always talking about models of the world and not about the world itself. Furthermore, in reality we cannot observe the exact mathematized laws of physics that are taught in science lessons. But without discussing the fact that we are modelling the world in physics lessons, the learners might believe that physics is magic – they are not able to understand it. For this reason we modified the framework of ‘Multiperspective Modelling’ (Böhm, 2012) to explain the development of understanding physics (see figure 1). In our special case we do not need the separation of the scientific (didacticised) model in different model perspectives (Böhm, Pospiech, Narciss & Körndle, 2012). The framework is based on ideas of (1) model theory (Stachowik, 1973; Kircher 1995; Hägele, 2000) and (2) mental models (Norman, 1983).

In a second step we use the theoretical framework to analyse an experiment. Normally physicists develop an experiment to prove a theory (verification), to gain new information or data (the basis of a new theory) or to illustrate a special effect in a more detailed way. We discuss the experiment ‘Raisin Lift’ – used by physics teachers – to illustrate the phenomenon of buoyancy. With this analysis we get an idea about finding the answer to the second question. The main point is that physicists always develop an experiment to focus on physics phenomena like buoyancy, and all related interpretations only focus on the experiment. But do all persons, also non-physicists, get the same information or data from the experiment? After discussing the experiment ‘Raisin Lift’ we draw conclusions about what teachers should do in science lessons with little children.

Based on these conclusions we developed a course for primary school teacher students. Our main aim was to tackle the two problems discussed above and to change students’ minds about science teaching. They should learn how scientists work and think and get confident about teaching science to little children in primary school.

To investigate students’ attitudes about science we used the psychological term of motivation. When students are not interested in science and worry about teaching science they have a lower motivation than if they are interested. In our investigation of the special science course we used a mixed method approach to evaluate the different attitudes of the students about science teaching before and after the course.

The Didactic Model – development of understanding physics

The didactic model (see figure 1) is based on a triple digit relation: (A) the natural phenomenon, (B) the scientific (didacticised) model of the phenomenon and (C) the learner (Kircher, 1995).

In (primary) school we cannot teach at the same high level like in science courses at the university. We are educating young children – novices in physics. Therefore we have to develop special didactised models for the teaching and learning process. This does not mean a simple reduction of content but a reconstruction. The teacher (see figure 1, B) should consider the prior knowledge of the students and the misconceptions (based on research) for the development of the didactised model of the scientific model.

According to this framework the learner (see figure 1, C) has two mental models to handle with. The fist one is based on the learner’s own interaction with the natural phenomenon and his/her own observations. The second one comes from the interaction with the didactised model of this phenomenon. During both processes of model construction misconceptions can occur in the students’ minds.
Figure 1. Heuristic framework for describing and exploring the process of understanding a physics phenomenon through science instruction (Böhm, 2012)

The learner is now confronted with the challenging task to compare both mental models and to combine the different models - as far as possible - to a new mental model of the phenomenon. This is a very complex process and it is the main cause of misunderstandings in the learning process. If the learner is not able to combine both models to one model, both mental models are existing further side by side. A fairly long time later the learners return to their own everyday experience, mostly based on their observations and explanations of the phenomenon. A logical consequence is that – if the two mental models are totally different – the learner overcomes his/her lack of understanding by root learning.

We usually have two more problems: (1) the teachers do not consider all students’ misconceptions or (2) their developed didacticised model causes new misconceptions in students’ minds. So – maybe - we have a never-ending circle consisting of students’ misconceptions and teachers’ especially developed didacticised models.

The main aim for the teacher is to foster the students’ learning process by monitoring the misconceptions coming to the learner’s minds during the processes described above. The teacher has to be an expert in physics and an expert in developing didacticised models for students’ special needs in the learning process. At any time the teacher must consider the possibility of two different signals (1) from the reality itself and (2) from teachers’ didacticised models of the reality.

We want to transfer these ideas to the analysis of the learning process during a science experiment. There we can also find two different views: (1) what a teacher intends (We call it “Looking through the physicist’s eyes”; see figure 1: a physicist starts from B or looks from B to A)) and (2) what students observe (and interpret in their minds) during the experiment (see figure 1: The learner looks from C to A.). We want to explain these processes using the “Raisin Lift Experiment”.

The Experiment: Raisin Lift

Take a glass of mineral water with gas and put a couple of raisins (figure 2) in it. After a few seconds the raisins will be dancing up and down. It looks as if the raisins want to clear the water from the bubbles of carbon dioxide.
Looking through the physicist’s eyes’ you see buoyancy. More and more carbon dioxide bubbles arise on the raisins’ rough edges. If there are enough bubbles at the raisin, the mean density of the ‘raisin-carbon dioxide bubble-combination’ is lower than the density of the water. As a consequence the raisin goes up. Arriving at the top of the water surface some bubbles are gone. Then the mean density of the ‘raisin-bubble-combination’ is higher than water and the raisin drops down. A complete description of the physics behind the experiment can be found in Schlichting’s article (1991). But can children ‘see’ the explanation ‘buoyancy’ by doing the following activities: perceiving, observing, examining, describing, comparing, distinguishing and labelling? Since these are the requested activities for primary school students (Perspective Frame of General Education in primary school, GSU, 2002) they have to practice them in the science lessons.

This experiment is generally done with sparkling water and a couple of raisins (A physicist knows that we need water aerated with carbon dioxide to get enough bubbles at the raisins.).

Which scientific insights can be obtained and which questions arise in the learners’ minds? Do students really observe the same like the physicists? If we look more precisely at the process, we observe the formation of bubbles at the raisins. At this point a lot of questions arise: How do the bubbles begin to develop and why? Are they developing only at the raisins or also on other objects? Is the sparkling water necessary or can we use other fluids? Here you can see that children may have many more questions that do not arise when we look through the physicist’s eyes’. In order to find the answers, much more interaction with the phenomenon (experiments) is necessary.

Doing the experiment with natural water again we can also observe the formation of carbon dioxide bubbles (figure 3, B), but the raisin does not start to dance. Why does the raisin not rise? Why are there not enough bubbles?

Normally physics teachers do not talk about all these different questions that the children generate straight from their observation. They are following their own ways – teaching the buoyancy phenomenon to the
children. Getting different information: (1) of their own observations (figure 3) and (2) from the teacher’s perspective (didactised model) of the buoyancy, the children develop two different mental models of the same phenomenon. Bringing these two mental models together more questions arise: “Why does the teacher only see the buoyancy phenomenon, nothing else? … Why are not more carbon dioxide bubbles at the raisin in the natural water?

Discussing the raisin lift according to the previously presented framework (see figure 1) we could show different perspectives (of the learner and the teacher) of the same experiment.

With the framework the student teachers get a manageable instrument for analyzing different perspectives in the learning process – especially for a very critical reflection of an experiment. Analysing the “Raisin Lift Experiment” we could show the teacher’s new challenge: He has to create a connection between his didactised model and students’ observations (mental model, questions) of it (see figure 1: B to C: Which data does the the didactised model provide for the learner?). Based on these ideas we developed a special course for primary school teacher students.

Science Course for primary school teacher students

In the first lessons (see figure 4) the students got familiar with the framework of “Multiperspective Modelling” which explains the development of understanding physics.

<table>
<thead>
<tr>
<th>Science Course for Primary School Teacher Students</th>
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<tbody>
<tr>
<td><strong>Lesson 1 - 3</strong></td>
</tr>
<tr>
<td>Students’ motivation pre-test</td>
</tr>
<tr>
<td>Framework ‘Multiperspective Modelling’</td>
</tr>
<tr>
<td>Development of understanding physics</td>
</tr>
<tr>
<td>Example: mirror image</td>
</tr>
<tr>
<td><strong>Lesson 4 - 11</strong></td>
</tr>
<tr>
<td><strong>Topics of Group Presentation</strong></td>
</tr>
<tr>
<td>- light experiments</td>
</tr>
<tr>
<td>- experiments with air</td>
</tr>
<tr>
<td>- water</td>
</tr>
<tr>
<td>- water cycle, hydrological cycle</td>
</tr>
<tr>
<td>- weather (and matching outfit)</td>
</tr>
<tr>
<td>- forces of wind and water (natural forces)</td>
</tr>
<tr>
<td>- fire</td>
</tr>
<tr>
<td><strong>Lesson 12 - 13</strong></td>
</tr>
<tr>
<td><strong>Experiment Fair</strong></td>
</tr>
<tr>
<td>Two groups of primary school students come to the university.</td>
</tr>
<tr>
<td><strong>Lesson 14</strong></td>
</tr>
<tr>
<td>- Students’ motivation post-test</td>
</tr>
<tr>
<td>- oral feedback</td>
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</tbody>
</table>

Figure 4. Structure and content of the science course for primary school teacher students

The application of the framework was explained with the phenomenon “mirror image”. In the next eight lessons the students presented different science topics (e. g. experiments with light, air, water, fire). All of these topics can be found in the curriculum of the primary school in the subject General Knowledge.

In our investigation the primary education students should develop an experiment for younger children. According to the didactic model they have to discuss two perspectives: (1) Which information do the children get during the exact observation of the experiment? and (2) Which didactised model does the teacher want to teach to the children and which particular objectives are addressed by this model? After
the preparation of the experiments and the group discussion about it we invited two groups of primary school children. We organized a little experiment fair. Every primary education student was responsible for one experiment and had to present it on a table. The children were free to walk around the experiment tables and stop at an interesting table.

The primary education students’ motivation before (first session) and after (14th session) the special course was analysed. We used the concept of motivation to gain more knowledge about the change of students’ opinions about science and science teaching.

**Method(s)**

**Design**

The science course for primary education students consisted of 14 lessons (90 minutes each) and took place in the winter semester 2011/12 (see figure 4). In a special course (N=45) for primary education students we used this framework to prepare small science experiments for children. Every student had to prepare his/her experiment according to this framework, to gain practical experience by explaining this experiment to young children and to reflect this process theoretically. To evaluate we used a mixed-method approach including the assessment of students’ motivation prior to and after the course, as well as students’ reflections and feedback, and the teacher’s observations and feedback

**Participants**

45 (30 female) primary school teacher students (undergraduate studies) participated in the study during the regular seminar “Experiments for little children” focussed on natural science at Technical University Dresden. 33 (30 female) participated in the pre- and post- test. All of them had physics lessons in school from grade 6 to 12, but most of them do not like physics at all.

**Material**

For the evaluation of the special science course we used a mixed method approach integrating (1) a motivation questionnaire, (2) observations and reflections from the teacher and students’ oral feedback, and (3) the results of the reviewed students’ papers.

**Motivation questionnaire.** Students’ motivation was assessed before and after the special course with the Likert-scaled Expectancy-Value-Form (EVF-LM) to assess domain-specific Learning Motivation (Narciss, 2006). The 17-item survey was divided into three scales that assessed students’ (1) intrinsic value (8 items; Cronbach’s alpha pre/post: .9/.75), (2) perceived competence and attainment value (4 items; Cronbach’s alpha pre/post: .81/.77) and (3) cost (5 items; Cronbach’s alpha pre/post: .78/.78). Students responded to all items on a 6-point scale with anchors of 1 (Very true for me.) and 6 (Not at all true for me.). The statement “I am very interested in science.” shows the interest of the learner and “I enjoy explaining science issues.” shows his joy at the activity, both address the intrinsic value. Two examples for perceived competence and attainment value are: “I think that I am talented at explaining scientific topics.” and “Explaining scientific topics is an exciting challenge for me.”. How difficult it is to teach science shows the conclusion “Teaching science is laborious.” (for all items see appendix A). We additionally collected oral feedback and a written assignment (see appendix A for the task) about an experiment of every student after the course.

**Students’ and teachers feedback on the course.** After the course the students were asked to provide oral feedback on the perceived learning experience and their deeper understanding of science teaching. They had the chance to give the feedback straight after the course or during the final discussion with the teacher about the written paper. Teacher’s feedback was about the perceived joy and interest of the students in science experiments and the observed preparation of the students for their own presentations.

**Students’ paper review by the teacher.** We analysed students’ papers according to the following criteria: (1) description of the phenomenon, (2) conclusion about the implementation of the experiment, (3) aims, (4) description of the experiment and (5) reflection.
Statistical analysis
First we run a two-factor analysis of the 17 items in the questionnaire for each of the pre- and post-test. The factor analysis is conducted in order to test the matching of the factor structure and also to ensure that we are using the same construct in the pre- and post-test. The data on students’ feedback and teacher’s observations were analysed following the principles of directed qualitative content analysis (Hsieh & Shannon, 2005).

3. Data and findings
A factor analysis of the EVF-LM confirmed the three factors predicted by Narciss (2006) for the present data: (1) intrinsic value, (2) perceived competence and attainment value and (3) cost. The internal consistency of all three factors in the pre- and post-test was good. Cronbach's alpha ranges between .75 and .90. The scales explain 65.5% of the variance. The means of the three factors in the pre- and post-test are shown in table 1.

Table 1. Means, standard derivation and Cronbach's $\alpha$ of students’ answers in 17 questions (Likert-scaled 1-6) in the pre- and post-test in the three factors of motivation: (1) intrinsic value, (2) perceived competence and attainment value and (3) cost.

<table>
<thead>
<tr>
<th>Scale Item</th>
<th>Mean pre</th>
<th>Mean post</th>
<th>SD pre</th>
<th>SD post</th>
<th>Cronbach's $\alpha$ pre</th>
<th>Cronbach's $\alpha$ post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic value</td>
<td>8</td>
<td>2.87</td>
<td>.82</td>
<td>.52</td>
<td>.90</td>
<td>.75</td>
</tr>
<tr>
<td>Perceived competence and Attainment value</td>
<td>4</td>
<td>3.86</td>
<td>.67</td>
<td>.52</td>
<td>.81</td>
<td>.77</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
<td>3.07</td>
<td>.79</td>
<td>.79</td>
<td>.78</td>
<td>.78</td>
</tr>
</tbody>
</table>

We compared the means (see table 1) of each factor in the pre- and post-test with an ANOVA. There was a significant difference in all factors between pre- and post-test: (1) intrinsic value $F(33)=30.5$, $p=.00$, $\eta^2=.49$, (2) perceived competence and attainment value $F(33)=23.7$, $p=.00$, $\eta^2=.43$ and (3) cost $F(33)=39.3$, $p=.00$, $\eta^2=.55$.

The two factors (1) intrinsic value and (2) the perceived competence and attainment value are decreasing and the factor (3) cost increases (see figure 3).

![Figure 3. Means of the three factors of motivation in the pre- and post-test.](image)

The oral feedback provided by the students after the course was very positive. They told us that they had learnt a lot about science and how to teach science in primary school. But they also mentioned that before this...
course they would have not believed that science teaching was so extremely complex and time consuming. During the course they had realized that they had to consider so many aspects and different perspectives.

During the whole course the students were very interested and always well prepared for their own presentations. Yet, the teacher mentioned that the students were extremely cautious regarding asking questions. They did not want to show that they did not have the sufficient knowledge to the other students - they were concerned about asking the wrong questions.

Students’ marks on the paper ranged between very good and adequate / satisfactory (one third each: very good, good and satisfactory).

**Discussion and conclusions**

After the course and due to the positive oral feedback and all the students’ fun with the science experiments during the course we expected a better motivation of the students. Nevertheless students’ motivation in science teaching after the course was lower than before. What happened?

To answer this question, we have first to consider that all students have had science courses in school (up to seven years of physics lessons!). Furthermore, most of them were not very interested in science before, even though they had obtained fairly good degrees in science before, and even though they had obtained fairly good degrees in science (the sample included students who met the numerus clausus, a grade point average of 2.0 for matriculation at the university). With the good high school degree they might believe that they have more than enough knowledge in science to teach it in primary school. Thus, before the course the students had to some extent an ‘illusion of knowing’ - they are unaware and unskilled about science learning processes of younger children. Moreover, they did not care about their own attitude to science, because they do not consider the influence of their own motivation on the teaching and learning process of the children.

Many experiments in the course prepared by students were as ‘exciting’ as experiments in science-shows. Some examples:

1. Take a cooked egg and soot it (take it near a candle). After some minutes the egg will be sooted black. Then drop it into water. The sooted black surface starts to twinkle in the water.

2. Place a candle in a glass of water and light it up with a quick match. Later the candle will burn under the water surface.

3. Take a glass of water and put oil in it. The oil will be swimming on the water surface. Then put a couple of ink-drops on it. Wait. Then strew salt (with a salt cellar) on it. Now the ink-drops will run low though the oil and fall down to bottom of the glass. Why?

All the experiments have one thing in common – they are not easy to explain in scientific terms – in particular to primary school children. They are very complex and combine different scientific aspects. What should children learn by doing these experiments? Is there more than fun? At the beginning of the course, no primary education student was able to explain such experiments. They only wanted to use the experiments as an exciting event for motivation. Making fun and motivating children goes hand in hand for the students. At this moment they did not understand that fun might be a start but there should be more than fun afterwards.

The ‘Raisin Lift’ discussed above is also such an experiment. Most students believe that the bubble stream is taking the raisins up to the water surface. Other students know the fact that this has something to do with buoyancy. We argued before that is not possible for children to ‘see’ the explanation buoyancy - children see different aspects. They follow their own observations and they have different prior knowledge than their teachers. They do not even know the concept of buoyancy. The main task for children in primary school is learning to identify regularities in the experiment and draw conclusions from these observations.

In summary it can be said that two steps are necessary in the science course for primary school teacher students: (1) to explain the experiment to the students and (2) to discuss the experiment’s usability in primary school (Are children able to understand it?). To discuss only one experiment takes a long time (often one lesson).
Teaching science in primary school demands high teaching skills and expert knowledge. Teachers and teacher students are often unable to cope with this problem. They have to consider that younger children are totally open to the world – they do not look through the physicist’s eye – seeing a reduced and modelled world. They develop questions to the world – those are totally different from our view. If we consider this, looking for appropriate experiments for primary school is very complex and time-consuming.

“Teaching science is laborious.” – one statement in the questionnaire and the significant increase of the factor ‘cost’ shows that during the course the primary education students understood how difficult science teaching is. Teaching science in primary school needs a deep understanding of science – and the knowledge from seven high school years proofed to be not enough.

Thus, our main aim in future is to increase students’ deep understanding of scientific experiments and their competencies in science teaching. Primary education students must learn to look through the children’s eyes and through the scientists’ eyes. They have to know and understand the scientific explanation of all the experiments used in their classes. The challenging task for primary education students is to bring both perspectives together. On the one hand side, they have to foster the natural questions of the children and should not dominate them, and on the other hand side, they have to find ways to illustrate how these questions can be answered through scientific methods (e.g., by planning and running an experiment). More than one science teaching course like the one described here seems to be necessary, in order to offer students opportunities to train these skills and make the experience that “Explaining scientific topics is an exciting challenge”.

References


Appendix A. Write a paper about your experiment

Task:
1. Describe your chosen phenomenon exactly.
   (a) Which information do the children get during the exact observation of the experiment?
   (b) Which didactised model does the teacher want to teach to the children and which particular objectives does he want to achieve?
2. Describe your conclusions from your experiment in detail.
3. Which aim do you want to achieve with your experiment?
4. Describe your planned experiment exactly, run the experiment and write down your observation / measured data.
   (a) Make assumptions (hypotheses)
   (b) Plan the experiment; run it (Only change one variable).
   (c) Write down your observations and measured data.
   (d) Results
   (e) Conclusion
7. Reflection

Appendix B. Motivation Scale and items

Value
Intrinsic Value (8 items)
- I share the vision that explaining science issues in school is totally uninteresting.
- I enjoy explaining science issues to children.
- I enjoy teaching science issues very much.
- Explaining scientific topics is an exciting challenge for me.
- I am very interested in science.
- I like to develop special science explanations for children.
- Teaching science issues in school is very important to me.
- Teaching science issues is very boring.

Perceived competence and attainment value (4 items)
- Explaining science issues in school is easy for me.
- I am always satisfied with my explanations of science issues.
- I think that my didactical skills to explain science issues are very good.
- I think that I am talented at explaining scientific topics.

Cost (5 items)
- I am afraid of making mistakes teaching science issues in school.
- I share the idea that explaining science issues in school is exhausting.
- I am afraid of difficult explanations of science issues
- Teaching science is laborious.
- Developing science explanations is very difficult for me.
Primary School Teachers: Becoming Aware of the Relevance of their own Scientific Knowledge

F. Corni, University of Modena and Reggio Emilia, IT
H.U. Fuchs, Zurich University of Applied Sciences at Winterthur, CH
E. Giliberti, University of Modena and Reggio Emilia, IT
C. Mariani, University of Modena and Reggio Emilia, IT

Abstract

We present details of a physics course for prospective primary school teachers that is based upon the structures of figurative thought available already to young children. The structures referred to are those found in the Force Dynamic Gestalt of natural forces such as heat, water, wind, electricity, chemicals, or motion. The same structures figure prominently in the formal science of physics. We demonstrate how student teachers can profit greatly from an approach that builds on everyday language and everyday conceptualizations. Our experience shows that teachers trained in this manner become confident narrators of basic physical processes.

1. Introduction

Teaching science to children in primary school or physics to prospective teachers can be viewed as a single challenge. If the training of future teachers in the sciences does not clearly deal with how children’s minds approach nature, the professional training misses important points and becomes an exercise in futility and frustration.

Therefore, we have developed an approach to physics for student teachers that is mindful of the cognitive development of children and the way humans develop imaginative approaches to understanding nature. The approach relies on figurative structures of the human mind that are used to conceptualize not only natural, but also psychological and social phenomena. These figurative structures are pervasive in common as well as paradigmatic languages (Lakoff and Johnson, 1999; Johnson, 1987; Talmy, 2000). In a different context, similar structures have been identified by Bliss (2008) in children’s thought dealing with nature. Physics courses that contain elements of what we have built include those of Boohan (1996), Herrmann (2003), and Fuchs et al. (2008).

The concepts we are speaking of make use of three image schemas that form the basis of what Fuchs calls the gestalt of forces or, more formally, the Force Dynamic Gestalt (FDG) (Fuchs, 2007). The schemas are quantity (size), quality (intensity and its differences), and force or power. In physics, they correspond to the concepts of extensive quantity, intensive quantity, and energy, respectively. Basing one’s conceptualizations of natural processes upon the figurative structures of the FDG is expected to provide a solid grounding for school science and beyond.

If student teachers learn that physics is not the representation of a truth “out there” but a representation of human imagination reflected in natural language, and if they accept that they possess the power of thought reflected in this language, they become inclined to believe in their own power to use good natural language to be good narrators of things happening in nature. As a consequence, stories are a good tool for teaching physics to young children. In stories, the well-known elements of narrative understanding combine with the characters of natural forces (wind, fire, water, chemicals, light, food, motion, etc.) creating a world easily understood by children of various ages (Fuchs, 2012).

In the following sections, we will describe the course for student teachers in detail. Then we show and analyse data that demonstrate the development of these students toward professionalism in their teaching of physical science to children in primary school.

The main question we are interested in is to what extent our course allows prospective teachers to become good scientific educators, with a positive inclination towards physics and a solid disciplinary knowledge anchored to didactic activity.
Our approach raises some issues that will be addressed in the Summary. Among these is the relationship between conceptualizations resting on figurative structures of the human mind on the one hand and misconceptions (as they have been identified in physics education research) on the other. Still other questions deal with natural language as a possible barrier to the traditional culture of science. Our answers support the claim that teachers—who are not scientists—can become strong narrators of good science if they learn to master the figurative structures underlying modern science.

2. The course

At the Department of Education and Humanities of the University of Modena and Reggio Emilia, a physics course has been taught to prospective primary school teachers (second year of the degree in Primary Education, first semester of the 2011-2012 academic year) using the approach afforded by the aspects of the Force Dynamic Gestalt (quantity, quality, force/power). These aspects span various topics of physics and form the basis of our metaphorical understanding of forces of nature.

The first part (Part I) of the course (30 hours, attended by about 60 students) is devoted to the introduction of the physical topics. The topics covered are:

- Figurative thought, image schemes and the FDG of natural forces
- Extensive and conjugated intensive quantities (extended potentials) related to a physical process
- Fluids (quantity: volume, quality: pressure)
- Motion (quantity: momentum, quality: velocity)
- Thermal phenomena (quantity: entropy, quality: temperature)
- Electricity (quantity: charge, quality: electrical potential)
- Chemical substances (quantity: substance amount, quality: chemical potential)
- Energy (balance between quantity and change in quality among coupled processes in a cause-effect chain).

For each topic we analyse extensive and intensive quantities and their mutual relations leading to the concepts of capacitance, resistance, current, and energy. The goal is to supply students with simple concepts powerful enough to scientifically interpret everyday situations that might also be encountered in school.

The second part (Part II) of the course (30 hours, attended by the same group of about 60 students) provides the introduction to measurements and error handling, and the proposal of some laboratory experiments, measurements, and (graphical) search for simple proportionality relation executed by the students in groups of 4-6. In the last few hours (8 over 30 hours), it covers methodological issues where we treat theoretically the design of didactical activities for ages 5-11 which respect the cognitive and linguistic skills of children.

After these two parts, students can prepare for the final (oral) exam by submitting:

- a summary of a lesson on the topics covered during a period of the first part of the course (group activity);
- a didactical unit for primary school about a physical argument using stories, experiments and general activities (individual activity);
- a story for physics education (individual activity).

The last (optional and not assessed) part (Part III) of the course (16 hours, attended by 22 of the previous students) is a practical laboratory-type course and is available to students after the exam, at the beginning of the second semester. The students are personally involved in working with stories for physics education. After an introduction about the interplay between story schema (Egan, 1986) and character schema (Fuchs, 2012) and the analysis of some case studies taken from the stories presented for the exam, every student is invited to:
• review and correct the story created by him/herself and one created by another student for the exam;
• design a didactical unit around a given story (the course teacher gives the students a story about heat and asks them to design a didactical path for a primary school class, specifying activities, scheduling, materials, grouping, setting etc., and explaining every choice made);
• write a new story;
• discuss the new story with the course teacher;
• revise the new story according to the suggestions of the course teacher.

The focus of this paper is on two different groups of students: (A-students), i.e., all students that attended the compulsory parts I and II of the course; and (S-students), i.e., the students that attended parts I, II and III of the course (they are a subset of the A-students).

3. Method

The central question we are concerned with is whether or not our course is effective in allowing prospective teachers to become good scientific educators. We try to answer this question by investigating three main points:

Inclination towards physics and perceived personal skills

Effective knowledge of physics

Ability to design didactical activities for children

The data is obtained from the analysis of:

• voluntary anonymous questionnaires given to students where they had to rate their agreement to some statements on a discrete scale from 1 to 4, and had to answer some open questions;
• the stories produced by the S-students at the end of Part III of the course.

Ideally, we would have liked to give the same questionnaire to the A-students twice: first before the beginning of the mandatory parts of the course, and then after these parts (after the exams). Due to time constraints, we were only able to give the questionnaire to the A-students (which includes the future S-students) after the exam. To make up for the lack of pre-course data, we asked the students to answer the statements twice: once for their current state, and once for what they would have answered if they had been given the questionnaire before the course as well. Effectively, then, we asked the students to estimate the change effected in their ratings for the statements as a result of the course.

We gave the S-students the same questionnaire once again after the third part of the course. Here, we asked them to rate an effective perceived change (PC) in their answers to the statements effected by the final laboratory part of the course.

The numbers of returned questionnaires are: 32 for A-students and 18 for S-students. In what follows, we list and briefly describe the statements and open questions given to the students.

3.1 Inclination towards physics and perceived personal skills

3.1.1 Questionnaire statements concerning:
SI3: Physics has improved my curiosity towards scientific knowledge.

Statements about students’ feeling toward physics:

SF1: Physics is difficult in general;
SF2: Physics is difficult to understand for me;
SF3: Physics is interesting.

3.1.2 Open questions about students’ inclination toward Physics:

QI1: Has your inclination towards physics changed after the course (on a scale 0 to 4)?
   What was your inclination towards physics before the course?
   What is it now?

QI2: Has your vision of your work as a teacher changed?
   Describe how and in what sense it has changed.

QI3: Has your way of explaining an everyday natural phenomenon changed after the course (on a scale 0 to 4)?
   Describe in which way it changed and how you would have described the same phenomenon before the course.

3.1.3 Two questions concerning students teachers’ perceived suitability of the physics they have learned to teach children:

SS1: It is possible to teach physics well, using natural language.
SS2: Children cannot understand physics, because they are not capable of abstract thinking.

3.1.4 Two open questions about students’ perceived suitability of the physics they have learnt to teach children:

QS1: Is it possible to teach physics to primary school children?
   If yes, how?
   If no, why?

3.2 Effective knowledge of physics

For the authors, the effectiveness of the new knowledge of the students is related to their ability to approach everyday experiences in a scientific way. So, here, the disciplinary knowledge is evaluated through the students’ ability to describe nature using appropriate metaphorical and natural language.

The questionnaire presented two open questions about thermal phenomena that are part of our everyday experience:

QK1: This winter is particularly cold. What shall we do if the rooms of the house do not get warm enough?
   Which analogy could you use to explain your reasoning to a friend of yours?

QK2: The recipe to make a cake requires the cake to be baked in the oven at 180°C for 40 minutes. You want to prepare two cakes for a birthday party and you decide to bake both cakes at once. Do you have to change anything about the oven settings or baking times?
   Which analogy could you use to explain your reasoning to a friend of yours?

3.3 Ability to design didactical activities for children

The didactical ability was assessed in terms of:
3.3.1 the stories produced by the students;
3.3.2 an open question presenting a situation as it might actually arise at school:

QD1: As a teacher, you want to organize a school trip to a wind farm where electricity is produced by the wind. How can you prepare your students for the trip?

How would you organize the visit to the wind farm?

What can you do in the classroom after the trip?

4. Data and findings

Before presenting the results concerning the three points outlined above to answer our central question, we will briefly summarize the results obtained from the questionnaires. In the following table, we list the results for the statements described above. For each statement, we present the following average ratings given by the students: (ARP) Average Rating for the “Pre-Test”, i.e., their estimate of what they would have answered had they been given the questionnaire before the course already; (PC1) average Perceived Change in rating effected by the mandatory part of the course; (AR1) Average Rating after the mandatory part (AR1 = ARP + PC1); (PC2) second average Perceived Change effected by the voluntary laboratory course (S-Students only); (AR2) Average Rating after the voluntary part of the course (S-students only) (AR2 = AR1 + PC2).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>A-students</th>
<th>S-students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARP</td>
<td>PC1</td>
</tr>
<tr>
<td>SR1</td>
<td>1.53</td>
<td>1.87</td>
</tr>
<tr>
<td>SR2</td>
<td>1.5</td>
<td>2.03</td>
</tr>
<tr>
<td>SI1</td>
<td>1.83</td>
<td>1.6</td>
</tr>
<tr>
<td>SI2</td>
<td>1.43</td>
<td>1.3</td>
</tr>
<tr>
<td>SI3</td>
<td>1.53</td>
<td>1.3</td>
</tr>
<tr>
<td>SF1*</td>
<td>1.7</td>
<td>1.47</td>
</tr>
<tr>
<td>SF2*</td>
<td>1.69</td>
<td>1.38</td>
</tr>
<tr>
<td>SF3</td>
<td>2.03</td>
<td>1.24</td>
</tr>
<tr>
<td>SS1</td>
<td>1.8</td>
<td>1.63</td>
</tr>
<tr>
<td>SS2*</td>
<td>2.39</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Table I. Student average rating and differences to the questionnaire statements.

* marks the ratings complemented to 5 (see text).

A positive response to the course and our approach by the students should result in a positive PC1 and PC2: for the averages, this is the case for every item. Only 4% of the A-students and 2% of the S-students have given negative responses (negative changes), a very low fraction of students that is decreasing with the progress of the course.

Comparing the ARs of the A-students (AR1) and of the S-students (AR2), we can see, in general, another marked increase. This is consistent with the fact that using stories for physics education has strengthened their trust, both with regard to natural language as a powerful means for physics education, and to the perceived cognitive competences of the children.

The open questions have been analyzed in various ways, depending upon the topic of the question, as discussed below.
4.1 Inclination towards physics and perceived personal skills

4.1.1 Questionnaire statements concerning the students' feeling of the relevance of physics in their life (SR1, SR2).

The PC1s of the A-students are the highest, and the ones of the S-students (PC2) are among the highest of the entire list of statements. This is a strong message from the students about their PC. In particular, they declare a strong relevance of physics for their future work of teachers; that means our goal has been achieved, considering their lack in scientific knowledge as a result of their previous studies.

Statements concerning how students see nature and science (SI1, SI2, SI3).

In this case the PCs are medium. This indicates a significant PC, with a preferential interest for natural and life studies compared to technological or scientific studies.

Statements about students’ feeling toward physics (SF1, SF2, SF3).

The SF2 PC2 of S-students is the lowest and the SF2 AR1 of A-students is among the lowest of the entire list of statements confirming the difficulties of students with physics. This, with the results on the previous statements, creates a picture of these prospective teachers as positively inclined toward physics, though they are aware of their structural lack regarding disciplinary contents.

4.1.2 Open questions about students’ inclination toward Physics.

QI1.

All A- and S-students declare a positive change of inclination towards physics, with an average of 3.90 and 3.47, respectively. 8 S-students (44%) explicitly stressed that, after the compulsory part of the course, they had already changed their inclination. [Except for two students (one of whom claims an interest in physics without ever having studied it, whereas the other shows a generic optimistic inclination), all respondents say they had difficulties with physics and a negative feeling toward physics before our course.]

We found the following taxonomy of student difficulties and inclination towards physics. With the same items, we analyzed the A- and the S-students’ claims concerning their inclination towards physics before the course. Table II reports the occurrences of the various items.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulties</td>
<td></td>
</tr>
<tr>
<td>Complicated</td>
<td></td>
</tr>
<tr>
<td>Abstract, theoretical, use of formulas</td>
<td>16</td>
</tr>
<tr>
<td>Lack of interest</td>
<td></td>
</tr>
<tr>
<td>Inclinations</td>
<td></td>
</tr>
<tr>
<td>Feeling of fear/hate</td>
<td>4</td>
</tr>
<tr>
<td>Not suitable for children</td>
<td>2</td>
</tr>
</tbody>
</table>

A- and S-students’ answers concerning their inclination towards physics after the course can be classified as reported in Table III.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete, relevant to life, able to explain everyday phenomena</td>
<td>24</td>
</tr>
<tr>
<td>Interesting (in general)</td>
<td>2</td>
</tr>
<tr>
<td>Other positive answers</td>
<td>8</td>
</tr>
</tbody>
</table>

QI2.

100% of students say that a change has occurred after the course with regard to their vision of their future profession. The reason they give for this change is the range of perceived skills they developed during the course (as reported in Table IV).
Q13.

The main difference in the A- and the S-students’ opinions before and after the course consists, in particular, in the relevance of physics for explaining everyday life, compared with the previous prevalent opinion about physics as an abstract and theoretical subject.

4.1.3 Two questionnaire statements concerning students’ perceived suitability of the physics they have learnt to teach children (SS1, SS2).

The SS1 PC2 of S-students is the maximum of the entire table, meaning that the practical laboratory part of the course, in particular, has contributed decisively to students’ awareness of the power of natural language in teaching physics.

The SS2 values are typically extremes of all results. The PCs are the lowest and the ARP is the highest. Of course, a maximum value in ARP results in a minimum value in the PCs. This means that student teachers put trust in children’s abstract thought. To evaluate the contribution of the course to this belief, we can analyze the single student ratings, and consider the students that give an ARP of 4 for SS1 (meaning that they are in total disagreement with the negative statement about children’s abstract thought). Only 14% of A-students give an ARP less than 4.

4.1.4 Open questions about students’ perceived suitability of the physics they have learned to teach children (QS1).

All of the A- and S-students believe that it is possible to teach physics to children. In the answers of A- and S-students, a “constructivist” approach to physics and to reality as something we have to interpret emerges; they trust the use of stories and natural language in teaching science, and the role of experiments as an opportunity of speaking, thinking, and reasoning about phenomena.

[We used a control group of students who would take the course the following year which we are not reporting on in this paper. It is important to mention, however, that the control group views physics as a collection of statements about a truth independent of humans—a truth out there—rather than something that has to be constructed.]

4.2 Effective knowledge of physics

QK1, QK2.

Let us analyze the two open questions together. The problems posed concern everyday life. The aim of these questions is to demonstrate the metaphorical use of the aspects of the FDG in the language of students which proves a scientific inclination instead of a superficial way of solving common problems.

First, we evaluated our students’ explicit use of the terms “heat” and “temperature.” In QK1, the frequencies are 61% for A-students, and in QK2 they are 77%. Then we analyzed the natural language employed. 54% of A-students refer to heat and cold using terms that denote a metaphorical use of the substance image schema. Of the A-students, 30% refer explicitly to heat as an agent that flows. Moreover, only 12% of A-students refer to warm clothes as barrier to the outer cold or as a source of heat.

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Another indication of their mastery of physics is found in the answer to the request of an analogy to explain their reasoning to a friend. In QK1, 74% of A-students gave answers, and in QK2, the numbers were 50% (in most cases the students supply examples instead of analogies).

[These numbers may appear somewhat low to a scientist. Again, comparing to the control group, we get a different picture. The use of good scientific language is significantly higher for the A-students than for the control group.]

4.3 Ability to design didactical activities for children

4.3.1 Stories produced by the students.

The stories, created and revised during the optional laboratory part of the course have been analyzed according to the following criteria: appropriateness of (natural, not formal) language with children in mind, presence of a story schema that engages children affectively, presence of a natural force, presence and differentiation of the aspects of the FDG of natural forces. Table V reports the results found the 20 stories produced.

<table>
<thead>
<tr>
<th>CRITERION</th>
<th>First version</th>
<th>Revised version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of a story schema</td>
<td>85%</td>
<td>100%</td>
</tr>
<tr>
<td>Language appropriateness</td>
<td>90%</td>
<td>100%</td>
</tr>
<tr>
<td>Sentence length appropriateness</td>
<td>95%</td>
<td>100%</td>
</tr>
<tr>
<td>Presence of a natural force</td>
<td>60%</td>
<td>90%</td>
</tr>
<tr>
<td>Differentiation of FDG aspects</td>
<td>53%</td>
<td>73%</td>
</tr>
</tbody>
</table>

Many students produce stories with good story schemas already in the first version. They have more difficulties introducing scientific aspects (natural forces). Mostly, they are able to revise and correct their stories properly.

The language used is appropriate in 90% (100% after the revision) of cases, and sentences are of suitable length (95%, then 100%). Sometimes students tend to use some words taken from scientific formal language, but in the revision phase they agree that those words are unnecessary and that there are ways of explaining the same concept with natural language.

In few cases (10%), students introduce more than one main topic in the story (the task was to write a story on one topic), e.g. heat as well as water.

Referring to the aspects of the FDG, the preferred is force/power (present in 70% of the stories), then quality (65%), and finally quantity (55%). The aspects of the FDG are well differentiated in 53% of the cases (8 of 15 stories), and in 73% after the revision (11 of 15 stories).

The stories are mostly addressed to children age 3-5 (50%), or age 6-8 (45%); only 1 of 20 was written for older children of age 9-11.
4.3.2 Responding to a situation as it might actually arise at school.

QD1.

All students, attending or not attending the course, are affected by the stereotype of a school trip with the intervention of an "expert of science." In this stereotypic view the teacher, or the prospective teacher, leave the class in the hands of the expert. The preparation of the trip consist in explaining the functioning of a wind farm, or renewable energy, etc. Then, after the trip, they ascertain what the children have understood, collecting ideas of children. They might construct a model of a wind-mill, and make the children perform experiments with wind. To overcome this stereotype requires specific training so as to allow the teacher to remain the leader of the learning process.

5. Discussion and conclusions

The results of this investigation are preliminary. However they give us some valuable information.

First, starting with the figurative structure of scientific thought (Part I), rather than the disciplinary contents as they are usually found in the textbooks, allows the students—who often lack scientific grounding due to their previous studies or to their preconceived idea of the discipline—to become aware of their ability to understand and learn physics.

Moreover, the laboratory parts of the course (Part II and III) that have been described here provide the students with powerful knowledge of how children think. This is most important for future educators. The central role given to stories and to natural language provides bridge between the discipline and its didactics.

As a result of this investigation, the authors have obtained a clearer understanding of what to look for in the professional development of future primary school teachers. Our students express that they become aware of the power of natural language and narrative forms of science for comprehending nature. Our investigation has provided hints of a useful form of understanding of physical concepts and of the ability to make these concepts available in the classroom.

Let us now turn to some important issues that are raised by our approach to teacher education in the sciences, and by the changes proposed to how science can be taught in primary school classrooms.

Since the paradigmatic language of science is figurative at its core, there is no contradiction between learning about nature using the metaphors provided to us by our mind and learning to master important formal aspects of the sciences. At the level of image schemas and their metaphoric projections, common sense and science share a large set of concepts. The Force Dynamic Gestalt structures are as much elements of common thought as they are of formal theories of (macroscopic) physics (see Fuchs, 2007, 2010). This means that the ubiquitous problem of misconceptions does not arise here. It arises when figurative schematic thought is applied to concrete phenomena requiring detailed reasoning. At this point, reasoning may become faulty and lead to what are called misconceptions. Let us be concrete about the difference between basic concepts and misconceptions by considering an example. In a case involving engineering students, we have observed how they hesitated to put into a container a sensitive specimen previously heated. When asked, they replied that they felt the specimen could get even warmer and thus be destroyed. This reasoning follows from our bodily experience of putting on warm clothes—a living body gets warmer when wrapped up because of internal generation of heat. The concrete case of reasoning is incorrect; however, the underlying understanding of heat as a quantity that is contained in materials, can flow, and can be generated, is not. We can actually hope that, by learning about the powerful basic structures with which we conceptualize nature, reasoning may become easier. Our students understood quite readily that their hesitation was unwarranted and where the incorrect notion was coming from.

What about natural language and the culture of science? Are we not creating a rift between the science we wish our children to learn and their usage of language if we stress the utility of common language for science learning? Actually, the issue raised here is very similar to the one having to do with common sense notions and misconceptions: the problem lies elsewhere. Natural language using image schematic structures and their metaphoric projections are very much a part of formal science. What we are proposing here does not lead to language that is “unnatural” to the sciences, quite the contrary. As demonstrated in minute detail by the linguists Halliday (2004), Halliday and Martin (1993), and by Lemke (1990), it is science and science teaching that unnecessarily introduce “unnatural” language that alienates learners
(this refers to the tendency to nominalize expressions, and to careless usage of language that hides rather than uncovers fundamental meaning relations, i.e., semantic relations). In our opinion, if we follow the lead of traditional science and science teaching rather than that of modern cognitive science, linguistics, and modern macroscopic physics, we do our children a disservice.

6. References


6. Index of abbreviations.

FDG  Force Dynamic Gestalt

A-students  students that attended the compulsory part of the course and that filled in the voluntary questionnaire (32 in total)

S-students  students that attended the compulsory part and the optional laboratory part of the course and that filled in the voluntary questionnaire (18 in total)

AR1  A-students’ average rating to a questionnaire statement (from 1 to 4)

AR2  S-students’ average rating (scale extended effectively from 1 to 5)

ARP  students’ average post-evaluated rating to a questionnaire statement (from 1 to 4)

PC  perceived change (by students) of a variable

WCPE 2012, Istanbul, Turkey
Teacher Training Program with Active Learning Based on Physics by Inquiry

Kyoko Ishii, Yoshihide Yamada, Faculty of Education and Regional Studies, University of Fukui

Author Note: Kyoko Ishii and Yoshihide Yamada, Faculty of Education and Regional Studies, University of Fukui. Correspondence concerning this article should be addressed to Kyoko Ishii, Faculty of Education and Regional Studies, University of Fukui, Bunkyo, 3-9-1, Fukui-shi, Fukui, 910-8507, Japan

Abstract

We have developed a teacher training program aimed at deepening the scientific understanding of teachers-in-training and investigated the effects of using Physics by Inquiry (PBI). In Japan, many primary school teachers teach science but find it difficult, especially physics. Such teachers have likely not acquired in-depth knowledge of science during high school and college and have had few experiences that aroused their interest in learning science. Consequently, the teachers feel that they lack the understanding, knowledge, and skills necessary to teach science and physics. In this report, we introduce a development program on the teaching of electricity. A particularly challenging topic for teachers is electricity, even though it is taught at four grade levels in Japanese primary schools. Accordingly, we target the teaching of electricity in this study. According to previous research, electricity program of PBI has almost the same structure as the “Course of Study” established by the Japanese government (Ishii, K., Yuhki, C., Tanaka, M., 2000). We developed a program based on PBI for Japanese teachers-in-training. The content of the program is primarily arranged in a theoretical progression, starting with a single-bulb circuit, and advancing to electric current, series and parallel circuits, resistance, and voltage. The program is based on PBI, but we incorporate interactive lectures, peer instruction, and PhET simulation videos in order to promote interest and understanding in a large class. From pre test, typical misconception such as “electric charge is used up” and “a battery is a constant current source” has appeared. The program is effective for raising up students motivation and understanding from discourse analysis. Most effective topic is about current, because this program focused on current primarily. But some participants could not formulate a conception of the conservation of electric current in a circuit. Many participants continued to have difficulty conceptualizing resistance and voltage, it is consistent with previous findings. More detailed discourse analysis is in progress.

Keywords: teacher education, electric current, curriculum

Introduction

Most primary school teachers in Japan teach all subjects and find teaching science difficult, especially physics. A nationwide survey (Japan Science and Technology Agency, 2008) found that 67% of classroom teachers (N=545) encounter difficulty in teaching physics. Many teachers have not acquired in-depth knowledge of science during high school and college and have had few experiences that aroused their interest in learning science. Consequently, the teachers feel that they lack the understanding, knowledge, and skills necessary to teach science and physics. It has reported that Japanese students are good at memorization and reproducing scientific knowledge, but do not find science engaging, as seen from low motivation and confidence(Organisation for Economic Co-operation and Development, The Programme for International Student Assessment, 2007). PISA also reported that students in Japan are given few opportunities to engage in scientific inquiry at school. To facilitate scientific inquiry in the classroom, primary and secondary school teachers must develop their own science literacy. Accordingly, an effective and appealing program should be developed in order to provide teachers-in-training at university with an in-depth understanding of science and experience of inquiry.
Learning physics is difficult because its conceptual difficulties lead to misconceptions (Driver, R., Guesne, E., & Tiberghien, A., 1985). Recently, physics education has focused on social constructivism and active learning instead of lecture-based instruction. The Physics Education Research Group at the University of Maryland has developed effective programs for the active learning of physics (Redish, 2003). McDermott and the Physics Education Group at the University of Washington (1996) developed the most widely known program, *Physics by Inquiry* (PBI), which targets pre- and in-service K-12 teachers. In PBI, there are no lectures. Students form ideas through in-depth exploration of a few topics in laboratory. Students construct concepts through carefully guided instruction and experiments. The students are guided to construct scientific conceptions through an elicit-confront-resolve strategy. Learning by inquiry is effective for pre- and in-service teachers, as shown by their development of conceptual understanding and confidence (McDermott and Shaffer, 2000).

The aim of our research is to provide in-depth understanding and to raise motivation to teach science in the training of Japanese primary school teachers. Here we pose the following research questions:

(1) Is PBI used combined with an interactive lecture effective for teacher education in Japan?

(2) What difficulties are encountered when implementing PBI in Japanese teacher education?

Considering Japanese teacher education, we compared PBI and the “Course of Study” (COS) established by the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT). We selected electricity as the topic of study because it is a particularly difficult and frequently occurring topic in the Japanese science curriculum. We examined another program called *Tutorials in Introductory Physics* (TIP) (McDermott, Shaffer, and the Physics Education Group at the University of Washington, 2002), which was also developed by the Physics Education Group (1994) and is designed for group-learning activities in introductory university physics.

Developed by Engelhardt and Beichner (2004) to assess high school and university students’ understanding of direct-current resistive electric circuits, the “Determining and Interpreting Resistive Electric Circuit Concepts Test” (DIRECT) is used as a concept assessment instrument in education research (Baser, 2006). Improved conceptual understanding is measured as a gain in the DIRECT post-test score compared with the pre-test score (Hake, 1998; Redish, 2003). We use DIRECT along with discourse analysis to evaluate students’ performance and changes in their conceptual understanding.

**Methods**

**Program Development**

Science Education Team at Fukui University has developed a program consisting of two lessons based on the PBI electricity program, because electricity is a difficult and well-researched topic (McDermott and Shaffer, 1992). Moreover, electricity is prone to many common misconceptions. The major goal of PBI is to help students think of physics not as an established body of knowledge, but as an active process of inquiry in which they can participate. PBI contains narrative, experiments, exercises, and supplementary problems (McDermott and Physics Education Group, 1996), and is designed to provide students with the experiences listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Design of PBI (McDermott and Physics Education Group, 1996)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Students</strong></td>
</tr>
<tr>
<td>Start from their own observations</td>
</tr>
<tr>
<td>Develop basic physical concepts, use and interpret different forms of scientific representations</td>
</tr>
<tr>
<td>Construct explanatory models with predictive capability</td>
</tr>
<tr>
<td>Develop scientific reasoning skills</td>
</tr>
<tr>
<td>Practice in relating scientific concept, representations, and models to real world phenomena</td>
</tr>
</tbody>
</table>

WCPE 2012, Istanbul, Turkey
In Japan, compulsory education comprises primary and lower secondary school. The Ministry of Education, Culture, Sports, Science & Technology in Japan (MEXT) Course of Study (COS) defines the goals, subject content for each grade (MEXT, 2010). The stated goal of primary school science education is “to enable students to take an active interest in natural things and phenomena, and to carry out observations and experiments with a sense of purpose, while also fostering foundations for the ability to perform investigations scientifically and their positive attitude for doing so. To enable students to deepen understanding of natural things and phenomena and to cultivate scientific ways of looking and thinking.”

In line with the objectives of COS, teachers are required to cultivate a scientific perspective and way of thinking in students. PBI provides experience in “observation,” “model construction,” “reasoning,” and “representation.” Accordingly, PBI is suitable for cultivating a scientific way of thinking in Japanese teachers-in-training. Table 2 shows the content standards in the COS for electricity.

**Table 2. Content standards (electricity) (MEXT, 2010)**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Target concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>There are patterns of circuit connections that conduct electricity and others that do not.</td>
</tr>
<tr>
<td></td>
<td>There are materials that conduct electricity and others that do not.</td>
</tr>
<tr>
<td>4</td>
<td>The brightness of a light bulb and the rotation speed of a motor change with the number of connected dry-cell batteries and the configuration of the circuit.</td>
</tr>
<tr>
<td></td>
<td>A photocell can rotate a motor.</td>
</tr>
<tr>
<td>5</td>
<td>A coil carrying an electric current magnetizes an iron core.</td>
</tr>
<tr>
<td>6</td>
<td>Electricity can be generated and stored.</td>
</tr>
<tr>
<td></td>
<td>Electricity can be converted into light, sound, heat, etc.</td>
</tr>
<tr>
<td></td>
<td>The amount of heat generated by a heating wire depends on the thickness of the wire.</td>
</tr>
<tr>
<td>2*</td>
<td>Electric current and voltage are related.</td>
</tr>
<tr>
<td></td>
<td>There are patterns regarding the electric current flowing through each point on a circuit and the voltage at each segment.</td>
</tr>
<tr>
<td></td>
<td>Voltage and electric current are related, as discovered by students through experiments.</td>
</tr>
</tbody>
</table>

2*: 2nd grade in Lower secondary school.

The developed program covers direct-current electric circuits, a topic studied in the 3rd and 4th grades of primary school. To prepare a short program 180 min each for a total lesson time of 360 min, we utilized PBI, an interactive simulation using PhET (http://phet.colorado.edu), TIP (McDermott et al., 2002), the MEXT Course of Study, and Japanese textbooks. (Tokyoshoseki, 2011).

**First lesson of the program**

The first lesson of the program (Table 3) primarily covered circuits from parts 1.1–1.14 of PBI; this content is very similar to that studied by 3rd grade primary school students in Japan. The program was designed to follow PBI as closely as possible. One difference is that, although PBI establishes check points for instructors to monitor students’ progress, none were used in this lesson. It is because there are 100 students in a large lecture hall. Computer simulations (pHEt) of electric current and short circuits were added to raise the interest of students.
Table 3. Comparison of first lesson of the Fukui program with PBI, TIP, and COS

<table>
<thead>
<tr>
<th>Fukui-T</th>
<th>Check</th>
<th>PBI</th>
<th>Check</th>
<th>TIP</th>
<th>COS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1ABCD</td>
<td>Check</td>
<td>1.1 “Completion of a circuit”</td>
<td>1-IA</td>
<td>(3)</td>
<td></td>
</tr>
<tr>
<td>1.2A</td>
<td>Check</td>
<td>1.2 “Introduce the term “circuit””</td>
<td>X</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1.1EF</td>
<td>Check</td>
<td>1.3 “Examine a flashlight (bulb)”</td>
<td>1-ID</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2BCD</td>
<td>Check</td>
<td>1.4 “Operational definition of an electric circuit”</td>
<td>1-IB</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>PhET</td>
<td>Check</td>
<td>1.5 “Circuit with bulb, battery, and two wires”</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4A</td>
<td>Check</td>
<td>1.6 “Insert elements into the circuit”</td>
<td>1-IC</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1.1E</td>
<td>Check</td>
<td>1.7 “How to find an electrical connection”</td>
<td>X</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1.4C</td>
<td>Check</td>
<td>1.9 “Socket, holder, switch”</td>
<td>(3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4D</td>
<td>Check</td>
<td>1.10 “Consider a socket”</td>
<td>(3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3A, PhET</td>
<td>Check</td>
<td>1.11 “Short circuits”</td>
<td>(3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6A</td>
<td>Check</td>
<td>1.12 “Circuit diagrams”</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.13 Consider</td>
<td>Check</td>
<td>circuit diagrams</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.14 Draw a circuit diagram</td>
<td>Heat and resistance</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Second lesson of the program

The second lesson of the program was designed for small group inquiry (Table 4). The primary goal is for each student to construct a model of electric current through discussion and experiment. The lesson mainly follows “Model of electric current” and “Extending the model of electric current” based on PBI, but also incorporates aspects of TIP so that we can cover resistance and voltage in the limited class time available. We found that, because PBI is carefully designed as a step-by-step progression, it requires a considerable amount of time. Therefore, we skipped the experiments and exercises in parts 3.3–3.9 of PBI.
Table 4. Comparison of second lesson of the Fukui program with PBI, TIP, and COS

<table>
<thead>
<tr>
<th>Fukui-T</th>
<th>Check</th>
<th>PBI</th>
<th>Check</th>
<th>TIP</th>
<th>COS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1A</td>
<td>2. Model of electric current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2A</td>
<td>2.1* Observation for constructing model of current</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2 Representation of current model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3 consider the model of current</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2BCD</td>
<td>2.4* Two bulbs in series</td>
<td>1-IIA 2*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2D</td>
<td>X</td>
<td>2.5 consider in series circuit</td>
<td>X</td>
<td>1-IIB</td>
<td></td>
</tr>
<tr>
<td>2.3ABCDE</td>
<td>2.6* Two bulbs in parallel</td>
<td>1-IIABC 2*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3F</td>
<td>2.7 consider the current of parallel circuit</td>
<td>X</td>
<td>1-IIIDE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Extending the model of electric current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.1* Resistance</td>
<td>X</td>
<td>1-IIC 2*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5AB</td>
<td>3.2 Circuit with black box / current and resistance</td>
<td>2-I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5CD</td>
<td>X</td>
<td>3.3* Connection of series and parallel circuits</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.4 consider current in parallel circuit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5* Connection of series and parallel circuits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.6* Connection of complex series and parallel circuits</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.7* Connection of series and parallel circuits with switch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.8 consider current in complex parallel circuit</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.9 consider current in circuit with black box</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4AB</td>
<td>X</td>
<td>3.10* Limitations / need to extend the model</td>
<td>X</td>
<td>1-IV</td>
<td></td>
</tr>
<tr>
<td>2.6ABCDE</td>
<td>X</td>
<td>7. Voltage / potential difference</td>
<td>2-IIABC 2*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.7ABC</td>
<td>X</td>
<td>8. Extending the model / Kirchhoff’s second rule</td>
<td>2-IIABC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.8A</td>
<td>5. Ammeter, voltmeter</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>


Practice

The developed program was implemented during the 2012 spring term. Participants were 100 students at Fukui University, Faculty of Education and Regional Studies (65 women, 35 men, age 19–25 years). Most of the participants (91/100) were in the first year of a four-year teacher education program for primary school. Four participants were graduate students pursuing a teaching license. Most of the participants were majoring in a subject other than education and were pursuing a secondary school teaching license in their major subject. The participants had the following majors: mathematics or science, 19; English language or Japanese literature, 19; social studies, 15; art or physical education, 14; home economics or technology, 10; and special needs education, 10. All the participants had studied electricity up to lower secondary school. During high school, 33 participants had studied physics, and 17 of them reported that they did not understand it. Introductory science, including electricity, was studied during high school by 66 participants, of whom 40 reported that they did not understand it.

The first lesson was held on May 30 in a large lecture hall; all 100 participants attended. For experiments, 50 sets of equipment were set up so that the participants could work in pairs. The lesson was conducted by 2 faculty members and 5 teaching assistants.

The second lesson was held in a laboratory in four sessions. The students worked in groups of 3 or 4. The lesson was conducted by 2 faculty members and 2 teaching assistants. There were 5 check points where the students explained their thoughts to the staff.

Investigation

The conceptual understanding of the students was investigated by using DIRECT version 1.2. Participants took identical tests before the practice and 1–4 weeks afterward. The effect of the program was assessed in terms of the gain: gain=(class post-test average - class pre-test average)/(100-class pre-test average) (Hake, 1998).
The conversations of some groups were recorded with a digital voice recorder and video camera. Discourse analysis is in progress.

**Data and Findings**

In the pre-test, the overall mean score was 38.9% (N=100), but the score for the questions requiring a qualitative explanation (Q1, Q11, Q20) was 7.7%. The Q1 result showed that 72.0% students held the misconception that “electric charge is used up.” Another typical misconception was “a battery is a constant current source.” Participants had difficulty with the concept “potential difference is a property of the battery” (Q24).

The pre- and post-test scores are shown in Table 5. The post-test mean score was 46.4% (N=100). Some topics covered in DIRECT, so we administered the questions pertaining to only current, resistance, and voltage, which are topics specified in the COS for secondary schools.

**Table 5. DIRECT results**

<table>
<thead>
<tr>
<th>Number</th>
<th>Objective</th>
<th>Percentage Correct (N=100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Identify and explain a short circuit</td>
<td>pre-test (%)</td>
</tr>
<tr>
<td>19</td>
<td>Identify and explain a short circuit</td>
<td>post-test (%)</td>
</tr>
<tr>
<td>27</td>
<td>Identify and explain a short circuit</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Identify a complete circuit</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Identify a complete circuit</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>concept of resistance</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>concept of resistance</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>concept of resistance</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Apply the concept of power</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Apply the concept of power</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>conservation of energy</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>conservation of energy</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>conservation of current</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>conservation of current</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Explain the microscopic aspects of current flow</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Explain the microscopic aspects of current flow</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Explain the microscopic aspects of current flow</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>potential difference</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>potential difference</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>potential difference</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>potential difference to a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>potential difference to a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>potential difference to a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>potential difference to a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>potential difference to a variety of circuits</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Current and Voltage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>**: p&lt;0.01</td>
<td>**: p&lt;0.01</td>
</tr>
</tbody>
</table>

The gain is shown in Table 6. For current, the gain was high, because this program focused on current primarily. But some participants could not formulate a conception of the conservation of electric current in
a circuit. For resistance, the mean gain was 0.14. Therefore, many participants continued to have difficulty conceptualizing resistance. The lowest gain was observed for voltage, a result consistent with previous findings (Bowman and Aubrecht, 2007).

Table 6. DIRECT results

<table>
<thead>
<tr>
<th>Question number</th>
<th>Pre (%)</th>
<th>Post (%)</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>86</td>
<td>92</td>
<td>0.43</td>
</tr>
<tr>
<td>17</td>
<td>53</td>
<td>77</td>
<td>0.51</td>
</tr>
<tr>
<td>Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>31</td>
<td>0.1</td>
</tr>
<tr>
<td>14</td>
<td>25</td>
<td>41</td>
<td>0.21</td>
</tr>
<tr>
<td>23</td>
<td>33</td>
<td>41</td>
<td>0.12</td>
</tr>
<tr>
<td>Voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>59</td>
<td>77</td>
<td>0.44</td>
</tr>
<tr>
<td>24</td>
<td>21</td>
<td>12</td>
<td>-0.11</td>
</tr>
<tr>
<td>15</td>
<td>70</td>
<td>65</td>
<td>-0.17</td>
</tr>
<tr>
<td>28</td>
<td>37</td>
<td>31</td>
<td>-0.06</td>
</tr>
<tr>
<td>29</td>
<td>11</td>
<td>35</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Held in a large lecture hall, the interactive lecture featuring computer simulation videos appeared to be interesting and exciting for the students. Many students came to understand that “current is not used up” (Table 5, Q17). Compared with a conventional lecture, PBI entails much more active learning because of its small group discussions and collaboration.

Discourse analysis is in progress. We found that students reconstruct their conception through active discussion in the group. Table 7 shows one discussion on current flow. The participants discussed why three light bulbs become dimmer when connected to a battery in series than when connected to the battery individually. They attributed the phenomenon to the current being split. But when student D asked what was meant by “split,” student A found no point where the current could be split in the series circuit. Through their discussion, they constructed a conception of current flow.

Table 7. Discussion on current in a series circuit

B: Let’s see. I wonder why the bulbs get dimmer when they’re connected in series.
D: What is “split”? Split. I don’t understand what you mean by “split” at all.
C: I wonder how the current is split even in a series circuit.
D: What does “split” mean?
C: Crack! (Laugh)
A: But there is no point to split. (Laugh)
D: How does it split? (Laugh)

(Laugh)
D: Well, the current here [battery] is the same, isn’t it?
A: I got it! I’d say it remains one because it’s in series. It remains one ampere.
D: It stays at one, does it? One, one, one, one, one, one.
A: But, if it’s parallel, it becomes two here. Well?
D: It goes down to one here, here. OK?
B: Yes. Then, one, one, one, one. (Laugh)

(Laugh)

The participants engaged in active learning in this program. They enthusiastically discussed the topic and conducted experiments. Twelve participants completed all parts of the lessons. We observed that the participants were especially motivated in the second lesson. Eighteen participants finished part 2.7 (see Table 4), 38 students finished part 2.6, 20 students finished part 2.5, and 12 students finished part 2.4. Having 100 students in a lecture hall is not ideal for inquiry-based learning, because the instructors and teaching assistants cannot interact with the students well. The check points were effective for...
communicating with students and facilitating their inquiry. The students expressed their ideas when they engaged in eliciting, confronting, and resolving under the PBI paradigm. As in previous research by McDermott and Shaffer (1992), many students initially thought that “electric charge is used up” and “a battery is a constant current source.”

We found that considerable time is needed in order to construct correct scientific conception. PBI is well-designed with a step-by-step procedure but requires an appropriate number of facilitators to establish guided inquiry.

**Discussion and Conclusions**

A program using active learning based on PBI appears to be effective for teachers-in-training at university. The students studied electricity with interest and motivation. In particular, guided inquiry based on PBI provided a valuable experience for both the learners and instructors. DIRECT results indicate that conceptual difficulties were considerable and widely encountered. Discourse analysis suggests that expressing a concept elicited appropriation of expression, exchange of ideas, and reconstruction of the concept. Step-by-step exercises led the students to conceptual understanding. Moreover, teaching assistants were able to serve as facilitators rather than knowledge tellers. For the application of inquiry-based learning in Japanese teacher education, an essential requirement is that considerable time be devoted to the endeavor. Toward this end, substantial changes are needed in curriculum structure, notions of education, and social culture.

**Acknowledgements**

The authors thank Lillian C. McDermott, Paula R.L. Heron, Peter Shaffer, and the Physics Education Group of the University of Washington. We thank Donna Messina for assistance in investigating PBI with the TIP instructor guide. We acknowledge all the students and instructors who participated in this program; without their cooperation, this project would not have been possible.
APPENDIX: DIRECT questions (Q1, Q17, Q24)

Values in parentheses indicate pre- and post-test scores, respectively.

1) Is charge used up in the production of light in a light bulb?
   A) Yes, charge is used up. Charge moving through the filament produces “friction” which heats up the filament and produces light. (52%, 58%)
   B) Yes, charge is used up. Charge is emitted as photons and lost. (15%, 8%)
   C) Yes, charge is used up. Charge is absorbed by the filament and lost. (5%, 1%)
   D) No, charge is conserved. Charge is simply converted to another form such as heat or light. (24 %, 18%)
   E) No, charge is conserved. Charge moving through the filament produces “friction” which heats up the filament and produce light. (3%, 15%)[Correct]

17) From highest to lowest, rank the current at points 1, 2, 3, 4, 5, and 6.
   (A) 5, 1, 3, 2, 4, 6 (6%, 0%)
   (B) 5, 3, 1, 4, 2, 6 (5 %, 2%)
   (C) 5=6, 3=4, 1=2 (8%, 3%)
   (D) 5=6, 1=2=3=4 (53%, 77%) [Correct]
   (E) 1=2=3=4=5=6 (27%, 18%)

24) If you double the current through a battery, is the potential difference across the battery doubled?
   (A) Yes, because Ohm’s law says V=IR. (46%, 58%)
   (B) Yes, because as you increase the resistance, you increase the potential difference. (8%, 9%)
   (C) No, because as you double the current, you reduce the potential difference by half. (12%, 12%)
   (D) No, because the potential difference is a property of the battery. (21%, 12%) [Correct]
(E) No, because the potential difference is a property of the entire circuit. (10%, 9%)

References


Tokyoshoseki (2011), *Atarashii rika(New science)*, (In Japanese)
Fostering Pre-Service Science Teachers’ TPCK and Computer Self-Efficacy Beliefs in Teaching Middle School Physics Subjects†

Betül Timur, Science Education Program, Çanakkale Onsekiz Mart Üniversitesi, Çanakkale, Turkey, betultmr@gmail.com
Mehmet Fatih Taşar, Science Education Program, Gazi Üniversitesi, Ankara, Turkey, mftasar@gmail.com

Abstract
This study explored the development of Technological Pedagogical Content Knowledge (TPCK) in a technology and design course for pre-service science teachers during Spring Semester 2010. In this course, we aimed to foster pre-service science teachers’ TPCK. A cohort of 30 pre-service science teachers participated in this study in their sophomore years. The quantitative data included three pre-service science teachers, who taught selected topics from the primary science curriculum. During technology supported teaching sessions the participants were divided into small groups. We collected both quantitative and qualitative data in order to determine the nature of development of pre-service science teachers’ TPCK. The findings stemming from the quantitative data show that technology supported teachings foster pre-service science teachers’ TPCK confidences, self-efficacy beliefs towards microcomputer utilization in teaching (MUTEBI). Moreover, the findings emerging from the 3 multiple holistic cases revealed that engaging in technology supported teaching fosters five components of TPCK: i) knowledge, ii) purpose, iii) curriculum and curriculum materials, iv) instructional strategies, v) assessment. However, due to the nature of this study, such engagement did not foster teacher knowledge of students’ understandings, thinking, and learning in science with technology, which is one of the five components of TPCK.

Keywords: Technological Pedagogical Content Knowledge, Pedagogical Content Knowledge, Pre-Service Science Teachers, Technology Supported Teaching, Mixed Methods Research

1. Science Teachers’ Technological Pedagogical Content Knowledge (TPCK)
Technological pedagogical content knowledge (now known as TPCK or TPACK) has become a commonly referenced conceptual framework of teacher knowledge for technology integration within teacher education. TPCK is described as a complex interaction of content, pedagogy and technology and a discussion of successful integration of technology into instruction (Koehler & Mishra, 2008). In recent years researchers have described TPCK within the framework of Shulman’s (1987, 1986) description of pedagogical content knowledge (PCK). According to Shulman (1986, p.9) PCK “goes beyond the knowledge of subject matter per se to the dimension of subject matter knowledge for teaching” and PCK is the connection and relation of pedagogy and content knowledge. Table 1 shows ten scholars’ conceptualizations of PCK.

† This work was supported in part by TÜBİTAK under grant # 110K558
Table 1. Components of pedagogical content knowledge from different conceptualizations (Adapted from van Direl, Verloop & Vos, 1998; Park & Oliver, 2008)

<table>
<thead>
<tr>
<th>Scholars</th>
<th>Knowledge of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Purposes for teaching a subject matter</td>
</tr>
<tr>
<td>Schulman (1987)</td>
<td>d</td>
</tr>
<tr>
<td>Tamir (1988)</td>
<td>u</td>
</tr>
<tr>
<td>Grossman (1990)</td>
<td>PCK</td>
</tr>
<tr>
<td>Marks (1990)</td>
<td>u</td>
</tr>
<tr>
<td>Smith and Neale (1989)</td>
<td>PCK</td>
</tr>
<tr>
<td>Geddis et al. (1993)</td>
<td>u</td>
</tr>
<tr>
<td>Fernandez et al. (1995)</td>
<td>PCK</td>
</tr>
<tr>
<td>Magnusson et al. (1999)</td>
<td>PCK*</td>
</tr>
<tr>
<td>Hasweh (2005)</td>
<td>PCK</td>
</tr>
<tr>
<td>Loughran et al. (2006)</td>
<td>PCK</td>
</tr>
</tbody>
</table>

PCK: Author(s) included this subcategory as a component of PCK
d: Author(s) placed this subcategory outside of PCK as a distinct knowledge base for teaching.
u: Undiscussed subcategories

Researchers conceptualized PCK in the domain of teaching with technology under different schemes: “Margerum-Lays and Marx (2003) referred to PCK of educational technology, Slough and Connell (2006) used the term technological content knowledge, and Mishra and Koehler (2006) suggested the term technological pedagogical content knowledge (TPCK) – a comprehensive term that has prevailed in the literature” (as referred to and cited in Angeli & Valanides, 2009, p.155). TPCK can be described as how teachers understand educational technologies and PCK interacts with technology to produce effective teaching with technology.


1. Purposes and goals of teaching a specific content with technology (Orientation to teaching with technology) (OTTE)
2. Knowledge of instructional strategies and representations for teaching specific topics with technology (ISTE)
3. Knowledge of students’ understandings, thinking, and learning with technology in a particular subject (SUTE)
4. Knowledge of curricula and curriculum materials that integrate technology with learning in the subject area (CUTE)
5. Knowledge of assessment with technology (ASTE)

The data were formally analyzed by using the TPCK framework as a guide.
2. The Rationale
The turn of the 21st century marked the beginning of a much common and widespread use of computer technologies in science classrooms and practically everywhere else. Although it may not be sufficient for all teachers, several initiatives and efforts emerged in order to help science teachers to better understand the associated teaching methodologies and benefits of Computer Assisted Teaching (CAT) in science. Using technology in science classes requires teacher competencies in technology. Teachers need to maintain a coherent knowledge about content, pedagogy, and technology. Pre-service and in-service science teachers need to develop TPCK in the most effective ways to teach various science concepts, principles, and to create a technologically rich environment.

3. The Aim of the Study
This study aims to examine how senior pre-service science teachers’ TPCK develops the technology and design course that involves technology supported teaching.

4. The Research Questions
III. What is the pre-service science teachers’ perceived confidence level on four TPCK constructs (i.e., Technological knowledge (TK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and TPCK) before and after technology supported teaching?

IV. What is the effect of technology supported teaching on pre-service science teachers’ computer self-efficacy beliefs?

V. What kind of changes occur in five TPCK construct as pre-service science teachers plan and implement technology supported teaching?

5. Methodology
Mixed methods research methodology was employed in this study. One-group, pretest-posttest design was used to examine the TPCK development of an entire cohort of 30 pre-service teachers. The quantitative data were collected by the “Microcomputer Utilization in Teaching Efficacy Beliefs Instrument” (MUTEBI) (Riggs & Enochs, 1990) and “TPACK in Science Survey” (TPACKSS) (Graham, Burgoyne, Cantrell, Smith, Clair & Harris, 2009).
MUTEBI contains two sub-scale Personal Self-efficacy (SE) and Outcome Expediency (OE). These sub-scales are consistent with the Bandura’s self-efficacy theoretical construct (Bandura, 1977, 1994). SE sub-scale measures “teachers’ beliefs in their own ability to utilize the microcomputer for effective instruction” (p. 258), OE sub-scale measures “teachers’ beliefs with regard to the teacher responsibility for students ability or inability to utilize the microcomputer in the classroom” (p.258). Both surveys were administered to 30 pre-service science teachers as pre and post-tests. The qualitative data were obtained from three pre-service teachers who were selected among 30 pre-service science teachers based on maximum variety sampling, which is one of the purposive sampling methods. Hence, the quantitative data were triangulated by three pre-service science teachers’ pre-post interviews, observations during technology supported teaching, and artifacts (lesson plans, technology supported teaching feedback surveys, and technology enriched science modules).

6. Results and discussion

To address the question of perceived confidence level of pre-service science teachers’ related to the four TPCK constructs they were asked, “How would you rate your own confidence related to task associated?” as a pre and post-test. TPACKSS is a 5 point Likert type scale and includes 31 items in the areas of TK, TPK, TCK, and TPCK. Pre and post-test means were calculated for the four sub-scales and there were significant improvements between pre and post scores on all of the TPCK constructs as shown in Table 1. Also effect size (ES) was calculated to say whether or not our TPDP was having more effect on teachers’ computer self-efficacy beliefs. ES allow us to measure the strength of the relationship between two variables (Muijs, 2004). Cut points of ES proposed as; .01 weak, .06 moderate, .14 strong (Büyüköztürk, 2002, p.45-46). This means that pre-service science teachers’ TPCK confidence was improved as compared to the pre test.

Table 2. Results of Paired-Sample t-Tests for Factors of TPCK

<table>
<thead>
<tr>
<th>Sub-survey</th>
<th>N</th>
<th>Mean</th>
<th>S</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-TPCK</td>
<td>30</td>
<td>27.73</td>
<td>4.42</td>
<td>9.09</td>
<td>29</td>
<td>.000*</td>
<td>.739</td>
</tr>
<tr>
<td>Post-TPCK</td>
<td>30</td>
<td>35.70</td>
<td>2.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-TPK</td>
<td>30</td>
<td>24.03</td>
<td>4.37</td>
<td>7.86</td>
<td>29</td>
<td>.000*</td>
<td>.691</td>
</tr>
<tr>
<td>Post-TPK</td>
<td>30</td>
<td>30.67</td>
<td>2.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-TCK</td>
<td>30</td>
<td>16.07</td>
<td>4.92</td>
<td>6.48</td>
<td>29</td>
<td>.000*</td>
<td>.541</td>
</tr>
<tr>
<td>Post-TCK</td>
<td>30</td>
<td>21.27</td>
<td>1.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-TK</td>
<td>30</td>
<td>39.50</td>
<td>2.51</td>
<td>12.86</td>
<td>29</td>
<td>.000*</td>
<td>.847</td>
</tr>
<tr>
<td>Post-TK</td>
<td>30</td>
<td>51.57</td>
<td>4.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Survey</td>
<td>30</td>
<td>107.33</td>
<td>13.96</td>
<td>14.43</td>
<td>29</td>
<td>.000*</td>
<td>.877</td>
</tr>
<tr>
<td>Post-Survey</td>
<td>30</td>
<td>139.20</td>
<td>5.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p<.05

Table 2 shows before and after technology supported teaching pre-service science teachers’ TPCK confidence survey in general \([t(29)=14.43; p<.05]\) points, TPCK sub-factor \([t(29)=9.09; p<.05]\), TPB sub-factor \([t(29)=7.86 p<.05]\), TAB sub-factor \([t(29)=6.48; p<.05]\), and also TB sub-factor \([t(29)=12.86; p<.05]\), there were significant increase. In addition ES was calculated and technology supported teaching has strong effect on teachers’ TPCK confidence \((\eta^2_{\text{general}}=.877, \eta^2_{\text{TPCK}}=.739, \eta^2_{\text{TPK}}=.691, \eta^2_{\text{TCK}}=.541, \eta^2_{\text{TK}}=.847)\).

To address the effects of technology rich environments to pre-service science teachers’ computer self-efficacy belief pre-service science teachers administered MUTEBI as pre and post-test. Pre and post-test means were calculated for two of sub-scales and there was significant improvement between pre and post scores is shown in Table 3 (see below). This means that pre-service science teachers computer self-efficacy improved as compared to pre-test. Table 3 shows before and after technology supported teaching pre-service science teachers’ computer self-efficacy belief survey in general \([t(29)=2.09; p<.05]\) points and self efficacy (SE) sub-factor \([t(29)=6.86; p<.05]\) there was significant increase. But in Outcome Expectancy (OE)
points \[t(29)=7.13; \ p>.05\] there was no significant increase calculated. In addition ES was calculated and technology supported teaching has strong effect on teachers’ computer self-efficacy beliefs \(\eta^2\) general=.637, \(\eta^2\) SE=.619). But weak effect on teachers’ outcome expectancy \(\eta^2\) OE=.131).

Effect sizes included in Table 2 and 3 were calculated for all significant results. Effect sizes of approximately .01 are considered to be small, while .06 are moderate and .14 or above are large (Gren, Salkind & Akey, 2000). In this study calculated effect size is large \(ES>.14\) for sub-scales and for whole the survey.

To address the question of changes in TPCK occurs as pre-service teachers participate in technology supported teaching qualitative data was used. Pre and post interviews, observations during technology supported teaching and artifacts (lesson plans, technology supported teaching feedback surveys, and technology enriched science modules) were analyzed according to three components of TPCK. Moreover, the findings emerging from the three multiple holistic cases reveal that engaging in technology supported teaching fosters four of the components of TPCK (namely, knowledge of; purpose, curriculum and curriculum materials, instructional strategies and assessment, teaching with technology). However, due to the nature of the study, such engagement did not foster teacher knowledge of students’ understandings, thinking, and learning in science with technology, which is one of the five components of TPCK. It is concluded that technological knowledge, pedagogical knowledge and content knowledge are required for the development of technological pedagogical content knowledge. Furthermore, it is found that TPCK confidence, self-efficacy beliefs towards computer usage in teaching, professional experience and academic success is effective factor for the development of technological pedagogical content knowledge.

Table 3. Results of Paired-Sample t-tests for Factors of Micro Computer Utilization

<table>
<thead>
<tr>
<th>Sub-survey</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-OE</td>
<td>30</td>
<td>22.67</td>
<td>3.62</td>
<td>2.09</td>
<td>29</td>
<td>.046*</td>
<td>.131</td>
</tr>
<tr>
<td>Post-OE</td>
<td>30</td>
<td>23.67</td>
<td>2.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-SE</td>
<td>30</td>
<td>48.93</td>
<td>8.35</td>
<td>6.86</td>
<td>29</td>
<td>.000*</td>
<td>.619</td>
</tr>
<tr>
<td>Post-SE</td>
<td>30</td>
<td>59.87</td>
<td>4.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Survey</td>
<td>30</td>
<td>71.60</td>
<td>9.80</td>
<td>7.13</td>
<td>29</td>
<td>.000*</td>
<td>.637</td>
</tr>
<tr>
<td>Post-Survey</td>
<td>30</td>
<td>83.53</td>
<td>5.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* \(p<.05\)

7. References


In-service Teacher Training for the Use of Digital Technologies in Inquiry Based Activities

M. Kireš and Z. Ješková, Section of Physics Education, Institute of Physics, Faculty of Science P.J.Šafarik University in Košice, Slovakia
marian.kires@upjs.sk, zuzana.jeskova@upjs.sk

Abstract
The science education in Slovakia currently faces new challenges connected with the new curriculum reform running from 2009. The reform emphasizes the role of scientific inquiry in education that is in good correspondence with massive European movement oriented on implementation of Inquiry based science education. The contribution presents the key ideas of in-service teacher inquiry-based education within Slovak national project Modernization of education at lower and higher secondary schools which is aimed at the implementation of new ways of education enhanced by digital technologies. The main goals of the four-year national project (2009-2013) are creating instructional materials on the use of digital technologies and appropriate teaching methods and train up to 7000 in-service teachers for their reasonable application in the class. Among them there are 543 physics teachers who participate at the 9 days course aimed at the effective use of digital technologies in physics education. The paper presents examples of teacher training activities for key competences and scientific literacy development. The authors formulate conclusions from evaluation questionnaire used after the in-service teacher training graduation.

Introduction
One of the key problems of current society is the necessity to increase the interest of young generation towards science and science education. The society has changed a lot in the last years, information is widely available and easily gained and processed and hence the attitude of young people towards acquisition and adoption of information has changed a lot. Digital technologies nowadays offer a lot of new opportunities in education. They have brought hypertext information resources that have changed the system of linear data processing to the system of widely branched system enabling an easy-to-use and flexible connection and sharing of information.

The up-to-date information is accessible easily, so that it seems to be much less important to remember number of facts and knowledge as it had been before. The skills connected to the ability to search and find information, analyze and evaluate it critically are considered to be much more important than remembering facts. The ability to find, analyze, process and evaluate information and share, present, use and apply it effectively should belong to the skills that people entering the labour market are expected to master.

The wide research in the field of education in the past 20 years shows significant effects of the use of digital technologies (DT) on learning outcomes in science education. In science, in particular, where experimentation plays a key role, digital technologies can be a very effective tool in collecting, processing and analyzing data. Real-time experiments with datalogging (using interface and sensors), remotely-controlled experiments, experimentation on videoclips, and virtual experiments with the help of computer simulations could have strong educational benefits. However, the DT itself cannot help in better understanding of scientific concepts. Their effective use strongly depends on the teaching methods used in the class. The appropriate application of digital technologies in science offers students to assist and progress their learning and to engage them in higher-order thinking skills. One of the important aspects of teaching methods stressed by educators is that students must be physically and mentally engaged in their process of learning. R. Hake (1998) defines interactive engagement methods “as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers, and/or instructors”. The use of interactive methods in science education, in particular, has lead to the massive shift towards the wide use of inquiry methods generally called inquiry-based science education (IBSE).
According to Linn, Davis and Bell (2004) “Inquiry is the intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers and forming coherent arguments”. It means that in the process of teaching and learning we focus on the scientific process moving from facts (what we know) towards the process (how we know what we know). In this environment the role of teacher as well as the student has changed. Teacher is not a person who transfers the knowledge to students but he is more a facilitator of learning. Students do not only receive the knowledge but they are investigators who guide their own process of learning.

However, the transformation of education towards the regular application of these principles is not an easy task. It requires a lot of changes in curriculum, teaching materials as well as the consistent use of appropriate teaching methods. The latter requirement depends much on the well-educated teacher that is confident in such an environment. As a result, much attention should be paid to teacher training in the field of inquiry methods as well as digital technologies as their important element. To promote wide implementation across curriculum as well as education in general the support at wide national level is inevitable. In Slovakia there are currently huge national projects running, named Modernization of education at lower and higher secondary schools (2009-2013). There are 6850 teachers of different subjects involved in the project who participate in teacher training. The training involves three separate modules, i.e. Digital literacy of teacher, Modern digital technologies in teachers’ work and The use of digital technologies in the subject at lower and higher secondary schools. There is a total amount of 100 hours that are divided to 9 days (6 hours per day) of present training and the rest of distant learning with the help of LMS.

Methods
The teacher training aimed at modernization of education of higher and lower secondary schools are focused on the use of digital technologies and its effective use in the classroom. It is divided to three modules. Within each module there has been a teaching material developed in order to offer teachers a source of information about the topic. Based on the content of the three modules teaching materials there are teacher training organized and running for each of the modules.

Within the first module aimed at teachers’ digital literacy (6 or 12 hours of training in groups of 12 teachers), the focus is on the following issues: hardware and operating system, learning management system and e-learning, text editing, spreadsheets, presentations, co-operation between office suite parts, searching information through Internet, e-mail communication, on-line communication and videoconferencing systems (Lukáš, 2009).

The second module is focused on Modern digital technologies (18 hours of face to face training with 6 hours distance education part). The content of the course includes following parts (Kireš, 2010): Social networking sites for teachers - communication and community sites, blogs, sharing of educational content, Modern teacher digital workplace - the computer and its accessories, Classroom - my kingdom, Digital imaging - beamer, screen converter, microscope, Digital sound, image and video processing, Interactive didactics system - interactive whiteboard, tablet and voting system, Computer based laboratory - measurement, video measurement and digital data processing, Digital equipment for everyday life - GPS, wireless technologies, e-book reader.

The teaching material of the second module follows a common structure for each of the technology that involves:

- getting started - there are arguments why it is necessary to replace old instruments with the new ones, usually operated with computer,
- why to use - the series of successful school projects, examples of learning activities using modern technologies,
- how it works - concrete instruction and procedure how to use the technology,
- beyond the horizon - more details about the technology and its future perspectives,
- further links and references – additional resources for further learning.
The teaching material of the third module focuses on the use of digital technologies in teaching the specific subject. The basic idea is that it is not DT tools that students should be able to handle but it is their skills and competencies that can be enhanced by using DT tools (ICT in science, 2004). In the field of physics we focus on developing students’ capability (skills and competencies) to search and select information, organize and investigate, understand models and create models and control and monitor processes. For each of the skills there are given examples of appropriate DT tools that are most appropriate for the successful competency development (Ješková, 2010).

Searching and selecting: the use of DT allows students to search and select from a variety of information sources. These can be online sources (web portals, digital libraries, electronic journals), or offline sources of information (educational software, DVDs with e-content), that students use at different level.

Organizing and investigating: this DT competency is considered to be the most important in physics education. It can be successfully developed with the help of all kinds of experimentations enhanced by computer such as real experiment with the help of interface and sensors, videomeasurement, remotely-controlled experiment and virtual experiment with the help of computer simulations.

Models and modelling: dynamical modelling and modelling with the help of icons. In this field students can use DT at several levels, e.g. to understand existing models and investigate its behaviour under different conditions, to modify the model into a more complex one including other parameters, to create their own models and, moreover, they can compare the theory with experiment in order to prove the correctness of the model.

Control and monitoring processes: the use of DT allows monitoring physical conditions and reflecting upon the quality and quantity of the data collected, DT tools such as data-logging systems can also allow controlling the processes, writing a simple program students can control and operate a process or a device (fan, heater, bulbs, etc.).

Except from these four basic parts aimed at main competencies developed mainly within physics lessons complemented with examples of how to use DT, there are also exemplary lessons with teacher information and classroom materials developed. The teacher information involves detailed description of step-by-step teaching procedure (teaching methods and strategies used in the class) and where, how and why the selected DT is used. Classroom materials usually involve students’ worksheet or other materials for students to use in the class.
The written teaching materials (modules 1, 2, 3) are complemented with the digital library that is connected with the LMS for the teacher training management. Digital library represents a wide source of all of the developed materials that are continuously updated and are open for wide use of teachers from all over Slovakia.

**Data and findings**

Within the project there will be altogether 6850 teachers trained in the field of effective use of DT in education. Among them there are 543 lower and higher secondary school physics teachers. The teacher training and its effect on participating teachers have been monitored and evaluated with the help of questionnaires that participating teachers answered before and after training. Teachers expressed their level of mastering the specific digital technology described in the questionnaire item within the scale of 0...100% and hence the average score achieved before and after training has been compared. These numbers represent how teachers themselves feel about their own skills and competencies in the specific field. Here are the results achieved by the whole number of participants (module 1 and 2) and the results achieved by physics teachers, in particular (module 3).

For the evaluation of teachers’ level of digital literacy before and after the course the electronic questionnaire was created. The group of questions were focused on specific items: a) hardware and operating system, b) learning management system and e-learning, c) text editing, d) spreadsheets editing, e) development and use of presentations, f) co-operation between office suite parts, g) searching of information through Internet, h) e-mail communication, i) on-line communication and videoconferencing systems.

The results of all course participants (6850 teachers in total) are in Fig.3a. From the results of digital literacy questionnaire it can be seen that the lowest score before training was gained in the field of on-line communication and videoconferencing systems. However, after the training, the shift towards the higher digital literacy can be clearly seen in all of the items. The output results were a good basis for teachers to take part in the second module.

To compare the input and output knowledge and skills in the field of the modern digital technologies gained by participants there was a questionnaire prepared with several items concerning: a) social networking sites for teachers, b) modern teacher digital workplace, c) digital imaging, d) digital micro world view, e) digital image processing, f) digital sound processing, g) digital video processing, h) interactive whiteboard, i) tablet, j) e-voting, k) computer based laboratory (science teachers), l) GPS, digital musical instrument and wireless technologies (for non-science teachers). The final results are in Fig.3b. The lowest score before the training started was gained in the field of e-voting, computer based measurements and
wireless technologies. This is the result of the fact that schools are not equipped with these technologies. The output results show much higher level of teachers’ confidence in these fields. That was a good starting point for the next phase of teacher training aimed at the use of DT in the subject, itself.

**Figure 3.** a) Pre and post-questionnaire answers for teachers’ digital literacy questionnaire.

b) The input and output level of skills in the field of modern digital technologies

From the perspective of the implementation of DT in education the most important part was the third module of teacher training. A few days before and shortly after the course the participants answered the skills oriented questionnaire. The results of pre and post questionnaire of a group of 543 lower and upper secondary schools physics teachers are in Fig. 4.

**Figure 4.** The pre and post questionnaire results in the field of the use of DT in physics teaching

From the questionnaire results it can be seen that teachers competencies in the presented competencies, as expressed by teachers, have improved, nevertheless, they still feel lack of confidence in the field of models and modelling as well as computer-based measurements. This is not a promising result, since the development of students’ competencies and skills in modelling and experimentation belong to the basic components of inquiry-based science education. Moreover, the inevitable assumption of the real use of IBSE that focus mainly on the scientific process (involving experimentation and modelling), is a teacher mastering these technologies with high level of confidence. In this field much more training has to be carried out with continuous support of educators.
Discussion and Conclusions

Based on the results of questionnaires it can be seen that the level of the basic digital literacy of teacher training participants has been increased. This is considered just a starting point in order to develop skills and competencies in the field of modern digital technologies with focus on the successful and effective implementation in the subject itself. The use of digital technologies has to be used hand in hand with the appropriate teaching methods and in science education, in particular, respecting this fact, the use of DT can strongly enhance inquiry. The results of the questionnaires aimed at modern digital technologies and their implementation in physics show a positive effect towards the increased level of teachers’ confidence with different gain. However, the level achieved after the training corresponds to the instantaneous state of teachers attitude just after the training and as the results show, there are still some areas in which teachers do not feel too confident (such like experimentation with the help of computer as well as modelling techniques) that needs to be developed much more. Teachers, after the training, return back to their own school environments that can either support or not support too much their effort to change the way of teaching. They very often stay alone without mental and technical support from their own school. That’s why the teacher training is organized the way that there are always several teachers (at least two) from the same school participating at the training so that they can later cooperate and support each other in order to attract and educate other colleagues and hence create positive atmosphere towards the changes in education in wider scale. However, there is still a strong need to follow up with activities aimed at ongoing teacher education in this field to support already trained teachers as well as train other teachers towards successful implementation of the running educational reform.

Acknowledgement

This work is the result of the national projects Modernization of the education at primary and secondary schools (ITMS project codes: 26110130083, 26140130013, 26110130084, 26140130014) supported by the European Social Fund as well as the international 7FP project ESTABLISH (European Union’s Seventh Framework Programme FP7/2007-2013 under grant agreement n° 244749).

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The Complex Nature of Quantum Wavefunction and State Vector: Analysis of Case Studies on 3\textsuperscript{rd} Year Italian Physics Students

Marisa Michelini and Alberto Stefanel, Physics Education Research Unit, University of Udine, Italy
Giacomo Zuccarini, Physics Education Research Unit, University of Udine and, Department of Physics, La Sapienza University of Rome, Italy

Abstract

Research on university students ideas about connection between quantum formalism and concepts shows the existence of deep and persistent difficulties but plenty of topics in undergraduate curriculum still await exploration, including basic properties of quantum state representations. A first case study conducted by questionnaire and interview investigated the physical meaning and role ascribed by students to wavefunction (WF) properties. A second pilot study was conducted for the development of an investigation to explore how students link quantum formalism to concepts both in general terms and in the application context of specific problems. We report here the results of the first case study and of the pilot study, for what concerns the complex nature of the WF and quantum state vector. Data analysis of case studies shows how students are focused on the mathematical computational role of the use of complex numbers in quantum mechanics (QM), neglecting physical information encoded in the phase, displaying difficulties in distinguishing information contained respectively in $\psi$ and $|\psi|^2$. These results could help explain issues recognized in literature such as using probability amplitude instead of its square modulus to express probability.

Introduction

QM is taught in university physics courses throughout the world, where it usually plays a central role, because of its fundamental scientific content and wide technological applications. Nevertheless it is considered a ‘difficult’ topic due to the classically counterintuitive nature of its basic concepts (Mannila, Koponen, & Niskanen, 2002), and to the technical difficulties entailed by the highly mathematical formalism necessary to the representation of theoretical entities (Griffiths, 2005). In QM, physical quantities – called observables - are generally undefined, and a complete knowledge of system state allows only to predict the abstract sets of probabilities for measuring the various observables. On a formal level, the state of a system is not represented by a point in configuration space or phase space as in classical physics, but by a vector lying in a complex Hilbert space. Observables are not described by analytical functions, but by linear operators acting on the state. In general, making a prediction in QM requires to map physical quantities of the lab into entities of Hilbert space and then to translate the results into observations in real lab space (Singh, 2008).

Empirical studies on physics and engineering student understanding and conceptualization of QM show that, besides purely conceptual issues, students often can’t see through mathematics (Johnston, Crawford, & Fletcher, 1998; Sadaghiani, 2005). Instead, they develop survival strategies to perform reasonably well in the course work, which traditionally includes purely quantitative problems, e.g. solving Schrodinger equation with complicated potential energy and boundary conditions (Singh, 2008). But if they are asked to make use of formalism to draw qualitative inferences, they reveal blurred and highly fragmented conceptions on the way in which physical information is encoded in state formal representations (Sadaghiani, 2005; Singh et al., 2006; Singh, 2008; Robertson & Kohlme, 2010), on the role of operator structure of observables (Sadaghiani, 2005; Crouse, 2007; Singh et al., 2006; Singh, 2008; Gire & Manogue, 2008; Goldhaber et al., 2009) and in general of Hilbert space entities, which are mixed up with lab-space ones (Ambrose, 1999; Singh, 2008). Concerning quantum state properties, notable examples of problems are the difficulty to discriminate between closely related entities such as probability amplitude and probability, between possible measurement outcome and expectation value, and to recognize the nature...
of expectation value as an ensemble average (Sadaghiani, 2005; Singh et al., 2006; Singh, 2008; Robertson & Kohnle, 2010); interpreting FDO modulus as particle energy (Bao, 1999; Robertson & Kohnle, 2010); tracing discontinuous functions or with cusps (Singh, 2008; Singh & Zhu, 2009); asserting that real part of WF is null in classically forbidden regions (Ambrose, 1999, p. 150; McKagan et al., 2008a) and that only real coefficients correspond to eigenvalues and eigenstates (Ambrose, 1999, p. 225). These difficulties may persist in graduate students for the lack of in-depth discussion of conceptual meanings during university studies (Carr & McKagan, 2009).

Anyway, many aspects of non-relativistic QM curriculum have been barely touched by empirical research, even among basic features of the theory. The complex nature of WF and state vector is one of them. No research has been focused on the topic, and other studies have only given scant data concerning this aspect. Besides, except for above mentioned result on students ascribing different physical meanings to real and imaginary coefficients (Ambrose, 1999, p. 225), existing relevant issues have been elicited in a very specific context, i.e. graphical representation of WF (Ambrose, 1999, p. 150; McKagan et al., 2008a). Finally, research gives no information on student ideas about physical meaning of complex phases. As a consequence, a need arises to explore students ideas on the physical meaning and role of complex nature of quantum state formal representations. Complex spaces are indeed a structural feature of quantum theory, necessary to describe most physical situations and processes. Unlike phasor method in alternating circuits, this formal machinery cannot be considered only as a mathematical trick, as probability amplitudes must be represented by complex numbers (Feynman, 1965, p. 1-6, Townsend, 2000, p. 17). Exponential form ($Ae^{i\theta}$) is the most appropriate to highlight amplitude’s physical meaning, which is strictly related to stochastic character of quantum state. Modulus of probability amplitude (A) encodes information on probability distributions concerning the observable on whose base the state is expanded and commuting observables, as well as part of information concerning non-commuting ones. Phase of probability amplitude ($\theta$) completes information on the last category of observables (to be accurate, as quantum state is defined up to an arbitrary phase, we should speak about ‘information encoded in phase difference’ or ‘information encoded in phase relations’, but for simplicity’s sake we’ll refer to phase tout-court). Therefore, usefulness of phase in measurement often emerges after base change. For example, by means of Fourier transform we find that a real-valued (x) necessarily provides a null expectation value for momentum, while in all other cases knowing how imaginary phase varies with position is needed to calculate $<p>$. Structural role of phase emerges also in quantum interference, unitary time evolution and in Hilbert space structure. The last case can be better understood by observing that, in quantum framework, it’s not possible to use two-dimensional real Hilbert spaces to describe spin $\frac{1}{2}$ states (see Sakurai, 1994, pp. 6-10 for a discussion of this topic).

In this paper we report results of an investigation on student conceptions about the complex nature of quantum state representations, presenting data from a wider empirical research designed to 1) identify which role students attribute to formalism and 2) how students use formalism to describe QM properties and processes. The purpose of the research is to enrich knowledge on their learning problems and to find indication on the construction of teaching/learning proposals devised to overcome such difficulties. The research, relying on case study method, has been organized in two stages, and involved respectively 3 and 6 physics students belonging to different Italian universities. Both stages have been conducted with similar procedure: a written questionnaire, followed by individual interviews concerning their answers. In these studies we focus on the structural role of complex numbers and functions in QM, and on physical information encoded in phases, referring primarily to the elementary case of spatial component of state vector and WF. The research explores student conceptions in general terms and in the application context of specific problems, such as measurements in a Stern-Gerlach device, covering both discrete and continuous case.

**Instruments and Methods**

**Stage one**

As research calibration stage, a case study was designed on WF properties including a written questionnaire followed by interview to be administered to 3rd year physics students who are being exposed to QM...
undergraduate course. The questionnaire is made of four open qualitative essay questions concerning valid WFs, stochastic character of quantum state, complex nature of WF, WF as a description of the state at a single instant. Each of them is divided in sub-questions (figure 1).

Fig. 1 reports items 3.1-3.4, concerning complex nature of WF. The items are meant to investigate which role is ascribed by students to complex nature of quantum state (RQ3a); which meaning is ascribed to phases in the spatial component of WF (RQ3b) and if any meaning is ascribed to Re{ψ} and Im{ψ}, and eventually which ones (RQ3c).

3.1 Why do we use complex numbers in the description of the state of quantum systems?
3.2 Complex phases in ψ(x): do they have a physical meaning? If so, which one?
3.3 Do Re{ψ} and Im{ψ} play the same role in describing the state of a quantum system? Explain
3.4 How do Re{ψ} and Im{ψ} correspond to experimental outcomes?

Figure 1. Written questionnaire administered in the case study.

Semi-structured individual interviews of 20 minutes each were carried out some days after the written questionnaire, focusing on the discussion of questionnaire results and the research questions, to explore students’ way of thinking with more depth.

Data analysis was based on identification of reasoning classes defined by typical sentences related to concepts and formal aspects employed, and their relative relationship, according to empirical research methods. Individual profiles were built on the base of the specific research questions (RQ3).

Stage two

The second stage of the research has been designed to expand our focus on open issues, exploring students’ way of thinking about: basic features of quantum behavior; how physical information is encoded in QM state formalism; WF’s diagrams (how students draw and analyze them). A structured questionnaire of open questions with sub-questions was elaborated in terms of familiarity with formalism in facing specific problems, understanding of crucial aspects and peculiar entities of QM, awareness of the hierarchic structure of QM entities and their role in the interpretative framework. The two parts of the questionnaire were built on data from the first case study and deepen respectively: a) cultural aspects and reasoning paths on quantum description of state, superposition of states, properties and quantities (mutually exclusive and incompatible), measurement, quantum theory domain and determinism (Michelini, Santi & Stefanel, 2010; Battaglia et al., 2011) b) the connection between mathematical representation and concrete cases on valid WFs, stochastic character of WF, complex nature of quantum state vector and WF, WF as a description of the state at a point in time, time evolution (Singh, 2008).

In addition to general open-ended questions, concrete problems are included. Particular care has been taken in the exploration of relationships between concepts - formalism and representations. Individual interviews have been scheduled on each questionnaire item, organized in two sections: first a rogersian section and then semi-structured one.

In figure 2 are reported items 4 and 5, aimed at investigating complex nature of WF. In these items we focused on students ability to consider and make use of phase relationships to describe physical situations. Item 4, concerning discrete case, explores above mentioned topic in the specific context of Stern-Gerlach device, while item 5, concerning continuous case, is not related to any context. Item 4.1 is meant to examine how students link experimental outcomes (equal brightness of both spots) to information on initial state, how they encode such information in formalism (e.g. coefficients differing only by a phase, their square modulus being equal). Item 4.2 investigates how student deal with experimental prediction, how they use base change equations (provided in item’s text) to perform such prediction, and if they recognize phase’s role in this process. Also item 5 brings into play base change, leaving it to student’s management, to see if this procedure is handled as a formal black box, and if the physical role of phase in this formalism is recognized.
Figure 2. Items on student understanding of spatial WF phases.

Data gathering phases

The first stage was conducted in March 2012 on three 3rd year physics students from University of Perugia. Students were tested after they attended the first half of a standard course in QM which covered all relevant issues, and before taking the course exam. All participants had been high performing students through their undergraduate career (average grade 27-29/30), who had passed exams on analytical mechanics, complex analysis and linear algebra. Interviews were administered the day after the written questionnaire.

In June 2012 preliminary data were gathered using stage two methodologies. We tested one 3rd year physics student from University of Perugia, four from University of Calabria and one from University La Sapienza of Rome. Three undergraduate students have been interviewed, one in each university. All undergraduate students had followed QM course earlier in the same year and most of them (4/6) had passed the exam.

Data and findings

As a first thing, we report data from the preliminary case study. Item 3.1 in written questionnaire asks why complex numbers are used in the description of quantum state. Concerning this item and related parts of interview, the three students gave following answers:

S3 writes: ‘I think complex number are used because it’s convenient to write wave equations, containing sine and cosine, by means of complex numbers’.

S2 answers that ‘they are used because complex exponentials are a handy orthonormal base in $L^2$ space’.

In the individual interview he adds that ‘complex exponentials contain sine and cosine and are handy for series expansions’.

S1 didn’t answer question 3 in the written questionnaire. Asked to integrate this point during the interview, she states: ‘WFs can be expressed in terms of sine and cosine, so I can equivalently use complex numbers, which are easier to handle’.

Computational convenience in expressing sinusoidal function in complex notation is a relevant aspect emerging from all students’ answers, even if none of them explicitly cites Euler’s formula $e^{ix} = \cos(x) + i\sin(x)$. A connection to explicit physical aspects emerges only in student S3’s answer, in which an analogical link is activated to wave equations, covered in classical physics courses. Even the reference made by student S2 to the completeness of families of exponential functions in $L^2$ spaces, which has a significant conceptual meaning in QM, is focused exclusively on mathematical aspect. The physical
meaning of complex nature of quantum state description is evidently an open issue for these students, which has been confirmed by interviews. When explicitly asked if we can do without complex numbers in QM, two students answered affirmatively, either without giving any reason: ‘I’m quite convinced ... that we can’ (S1), or basing their reasoning on phasor’s analogy, where complex number role as computational aid is explicitly recognized (S3); the third expressed uncertainty on the subject, answering ‘I think that we ... could. But I don’t know why’ (S2). When we ask students about physical information encoded in spatial WF phase, we find them more disoriented than ever. None of the three students answered question 3.2-3.3-3.4 in the written text, and during interviews they used expressions like ‘I don’t know’. S1: ‘about phases [she hesitates] no, besides that [she hesitates] no, I can’t say anything about them’. Even if students showed to know the different representations of complex numbers both in written answers and in interviews, they revealed a complete splitting between mathematical knowledge of QM formalism and its conceptual content. In general, the presence of physical hooks in student reasoning, e.g. references to wave equations, is always aimed at supporting the ‘convenience’ aspect. Regarding the necessity or not of using complex numbers in QM, although in their initial answers student asserted the non-necessity of it, later in the interview they began contemplating the idea that complex numbers could have a structural role but weren’t able to find it, so it remained an open issue.

In the case study conducted in stage two we focused on the ways in which students connect experimental outcomes and formalism and how they make use of the complex nature of WF. In the following part of the section we label students with the first letter of the host city of their university and an integer sequential numbering. Regarding item 4.1, among 5 students answering the question, two of them express relations on \( \alpha \) and \( \beta \) (C1 and C2), three reconstruct the phenomenology they expect to observe (e.g. identifying the number of spots visible on screen), specifying the probability of single outcomes (P1), qualitatively describing how magnetic and spin momentum determine - on their opinion - experimental outcomes (C3 and C4), as in following example: ‘the beam is given by superposition of two spin states both in z-axis direction, but differently oriented. Running through Stern-Gerlach device, the atoms - which are subjected to magnetic force depending on spin - are deflected. For this reason the two atoms are sent in different direction, thus forming the final spots’ (C3). The fact that, on six students, three tried to reconstruct phenomenology and one didn’t answer this simple question, attests the need to discuss measuring process not only in abstract formal terms – as usually done in theoretical courses about QM, but also in operational ones. If we consider both written answers and interviews, results are the following: one student (C1) writes that ‘as the spots are identical \( \implies |\alpha|^2 = |\beta|^2 \); three students (C2, P1, R1) translate information on equal brightness of the spots in the assumption that \( \alpha = \beta = \frac{1}{\sqrt{2}} \), with further specifications such as ‘equal probability of z-component of spin being \( \uparrow_z \) or \( \downarrow_z \)’ (C2). When explicitly asked in the interview, C2 claims that coefficients \( \alpha, \beta \) and their square modulus have the same physical meaning. With the exception of one case, students show not to know which information is provided on initial state by experimental outcome. Although students are used to solving problems asking to reconstruct a WF, on the base of abstract information, translating an experimental/operative information into information on quantum state coefficients constitutes a problematic node for almost all students.

Item 4.2 concerns how student deal with experimental prediction, how they use base change equations (provided in item’s text) to perform such prediction, and if they recognize phase’s role in this process. Students C2 and C3 start from a state vector whose coefficients contain no phase difference, appropriately using given base change equations (see figure 3) and making predictions consistent with their initial assumption. From their answers it is evident that both consider \( \alpha \) and \( \beta \) as real positive numbers. C1, who in 4.1 had written \( |\alpha|^2 = |\beta|^2 \), expects to find here the same results as in previous item: ‘Both spots should have the same brightness, because the new beams should contain particles with spin \( \pm 1/2 \) with same probability’. The students presents a reconstruction of interaction process of atomic beams with Stern-Gerlach devices in terms of trajectories of single beams. Furthermore, his answer elicits another critical aspect about complex nature of coefficients: even where the relation between \( \alpha \) and \( \beta \) seems to have been correctly identified, this is not translated into recognition of the presence of an arbitrary phase, nor of a correct link between measurement of different spin components. Even when students identify a connection between experiment outcomes and state formalism, vector state reconstruction is made
without considering the complex nature of coefficients and different meaning of $\alpha$ and $|\alpha|^2$. A difficulty emerges in discriminating between physical meaning of coefficients and of their square modulus. Students P1, and R1 answer the question using only base change equations without referring to state vector, and concluding that only x spin-up spot will appear on screen because $|\uparrow_x\rangle\langle\uparrow_z| - |\downarrow_z\rangle\langle\downarrow_z| = 0 = |\downarrow_x\rangle\langle\downarrow_x|$. They interpret transformation equations as giving information on the system under test.

C2. ‘System superposition state vector as a function of $S_x$ eigenstates is:

$$\frac{1}{\sqrt{2}}(|\uparrow_x\rangle + |\downarrow_x\rangle) + \frac{1}{\sqrt{2}}(|\uparrow_x\rangle - |\downarrow_x\rangle) = \frac{2}{\sqrt{2}}|\uparrow_x\rangle = |\uparrow_x\rangle,$$

then we only have the spot corresponding to ad $S_x = |\uparrow_x\rangle$.

C3. Writing our state in x-axis direction, we find $(\alpha + \beta)|\uparrow_x\rangle + (\alpha - \beta)|\downarrow_x\rangle$. Similarly to what we’ve saw before [in item 4.1], the device will divide beams according to spin direction. Probability to see more or less markedly brighter spots depends on coefficients square modulus. We see immediately that first coefficient’s square modulus is greater than second one’s. Brighter spot will be spin up one.

**Figure 3.** examples of student answers to item 4.2

Regarding item 5, all students answer that Fourier transform allows to obtain system’s probability distribution in momentum space, starting from probability distribution in position space, as in following example: ‘given the fact that we are dealing with conjugate variables, we only need to apply a Fourier transform on position distribution’ (C1). In interviews, we asked students about quantum processes, procedures or physical situations they associate phase concept with. Two students quote ‘temporal phase factors’ (C2), or ‘time evolution of states. It represents a rotation of time independent Hamiltonian operator … a rotation in Hilbert space’ (R1). Moreover, both students add that spatial WF’s phase contain no physical information, as emerges in R1’s interview. Asked to specify if any information (and eventually which one) is encoded in the exponential component of the WF, written in the form $\psi(x) = A(x)e^{i\phi(x)}$, the student R1 answers: ‘looking at it in this way, I don’t think it contains any information. The only information we find in the WF is its square modulus, and the factor $e^{i\phi(x)}$ has unitary modulus’. These answers are coherent with already reported assumption that a coefficient and its square modulus have the same physical meaning. Specifically, it must be highlighted the consistency of C2 answers in interview portions related to item 4.2 and item 5, negating any physical information to phases both in discrete and continuous case. This analysis elicits that, though the formal aspect is subtle, behind it are hidden deep issues. The third student (P1), in the last part of its interview, states that $\psi(x)$ is different from its square modulus for what concerns its informative content: ‘maybe the WF contains some information more than its square modulus. I mean that I can sum two interfering WFs, and this interference is visible in square modulus for what concerns its informative content: ‘maybe the WF contains some information more than its square modulus. I mean that I can sum two interfering WFs, and this interference is visible in square modulus. But from square modulus I can’t obtain the two individual WFs who produce interference’. Moreover, discussing the physical meaning of the phases he sentences: ‘now I don’t know. But … in the end ... we are interested in square modulus ... but mathematically there’s more information in the WF than in its modulus’. In the answer of the students, the reference to interference phenomenological context seems to play an important role in recognizing that information encoded in $|\psi(x)|^2$ differs from the one encoded in $|\psi(x)|^2$, even if he can’t connect this difference to the physical meaning of complex phase function.

**Discussion and conclusion**

Quantum physics represents a cultural foundation for the present view of world. It is a basic knowledge for physics students and for other university students from many branches of science. Several empirical research on student understanding of QM concerning physics and engineering undergraduates have been conducted over the last fifteen years in order to identify how student conceptualize ideas of QM and which of them are most problematic. Many problem areas have been elicited, often tied to the lack of recognition of physical meaning of formal entities of the theory. Very few researches concern the role of complex nature and of imaginary phases of formal entities describing quantum state. A research has been designed to explore student ideas on this topic with the purpose to enrich knowledge on student learning problems and to find indication on the construction of teaching/learning proposal devised to overcome such difficulties. The research has been organized in two stages, both relying on case study method. In the
first stage three physics students have been involved in the second one six students. Both stages have been conducted with similar procedure: a written questionnaire has been administered to students, followed by individual interviews concerning their answers. Student answers to written questionnaires have been categorized, as well as oral sentences expressed in the interviews aimed at integrating written answers, to explore student’s ideas with more depth. From analysis indication have been drawn concerning relevant aspects. Students in our sample consider complex numbers only as a computational aid. Within the limits of our sample and methods, the question about student awareness of complex numbers role as structural aspect of QM state representation must be answered negatively. Informative content of phases does not emerge neither from resolution of simple problems in the written questionnaire Q2, nor from student discussion of vector and analytical representation of state in interviews. Students not only didn’t recognize the physical meaning of phases, but did not include their presence in calculations and comments, thus showing we are facing an unsolved conceptual understanding problem. In some cases, vector coefficients were assumed to be real positive number, which leaves an open question on the nature of the issue: is it related to an incorrect interpretation of probability amplitude as probability tout-court, or even to the habit to work prevalently with positive numbers, which could date back to pre-university education? Anyway we found a close correlation between this lack of recognition of phase role and the tendency to identify physical meaning of $\psi(x)$ with that of $|\psi(x)|^2$, which are interpreted as different ways to convey the same physical information. This aspect could open a further research topic, as issues concerning students’ use of coefficients and WFs to express probability, without squaring their modulus (well attested issues in literature e.g. Ambrose, 1999, p. 224; Singh, 2006, 2008; Robertson & Kohnle, 2010, Sadaghiani, 2005, p. 107, 130, 132.) could express lack of understanding of the physical meaning of spatial WF’s phase.

As in other fields of physics education research, we find that building student knowledge of QM on formalism and problem solving in contexts which are totally disconnected from phenomenological background, trains students to master formal tools and techniques, but affects their conceptual understanding of QM in a contradictory way. If they are asked to translate experimental/operative information into formal representation of quantum state, they can easily get lost. An important indication emerging from our investigation is that students need significant phenomenological context as a base for building the conceptual foundation of QM formal entities. Specifically, interference is a familiar context to students in which they can effectively recognize the role of complex nature of description of quantum state, and in particular of phases. We suggest that interference should be covered in physics courses (Feynman 1965), not only as a marginal topic, but assigning it a greater relevance for its conceptual role. At the same time, we need not to forget that phase relations are closely tied to information completeness of quantum state, and their significance emerges in more general situations, such as predictions on measurements of observables not commuting with the one on whose base the state is expanded. For this reason it’s important to emphasize in different contexts how and why physical information is encoded in complex phases.

References


The Pedagogical Challenge of Quantum Field Theory

Robert Lambourne, The Open University, UK,

Abstract

Quantum field theory arises from the fusion of special relativity and quantum physics. It is an important tool in many areas of physics and is at the heart of particle theory. Even string theory, which some see as a successor to quantum field theory, is still related to it and has many obvious links with it. Several students are exposed to elements of quantum field theory in the late stages of their undergraduate studies, though many do not experience their first full course in quantum field theory until they are graduate students. Whatever the context, most students agree that quantum field theory is a very hard subject, yet almost all the textbooks assert that quantum field theory is really a very straightforward subject, some even claim that it is easy. Why is there such a difference between those being taught and their expert guides? What is it that really makes quantum field theory hard for students, and why do so many of the experts appear to lose sight of the difficulty as they become more familiar with the field? This paper will review some of the concepts that students must master as they study quantum field theory, suggest reasons why their absorption a serious (yet apparently forgettable) challenge, and suggest lines of investigation that can throw further light on this under-researched but important area of pedagogic practice.

Introduction – the balance of educational physics

In the literature of educational physics much effort has been devoted to the many issues related to conceptual development. In the area of higher education much of the discussion has focussed on the teaching and learning of first year classes at the undergraduate level, and several clear results are generally agreed to have emerged. The same cannot be said of postgraduate education. The volume of educational literature relating to this sector is much smaller and although there are many accepted practices in the sector there are few relevant research results that can be described as accepted. Indeed, many readers will be familiar, at least at the anecdotal level, with PhD supervisors who would be surprised to learn that ‘Education’ might have anything to offer a student of physics at the postgraduate level.

This paper is a deliberate attempt to stimulate interest in the issues of conceptual learning at the postgraduate level. It arises mainly out of the author’s involvement in teaching (or attempting to teach) quantum field theory to postgraduate students, and the desire to see the development of a significant body of research-based literature that can have the same beneficial effect as that which already exists at the undergraduate level for topics such as mechanics and electromagnetism.

A key part of the challenge in investigating postgraduate physics education is that the concepts being taught are necessarily more complicated than those involved in undergraduate teaching. Consequently there is often disagreement, even between experts, about the meaning and significance of a concept, even one that may be essential to the field. This is certainly the case in quantum field theory where there is still much discussion about the nature of a quantum field (Teller, 2003) and even, in a strict mathematical sense, about the existence of non-trivial examples of interacting quantum fields (Douglas, 2004). In view of this, much of this paper is devoted to simply exposing the level of conceptual challenge that must be faced in quantum field theory before the familiar techniques and mechanisms of pedagogical investigation can be engaged.
Why is quantum field theory taught?

Quantum field theory (QFT) was created from the fusion of special relativity (SR) and quantum physics (QP). It originated in the mid-1920s, alongside the development of quantum mechanics (QM). At first it was intended to provide a way of describing physical fields, such as the electromagnetic field, that was consistent with the principles of quantum physics. Initially the view was that QM was applicable to systems that possessed a finite number of degrees of freedom, while QFT was appropriate for systems with an infinite number of degrees of freedom. However as quantum mechanics developed it became clear that attempts to formulate a relativistic quantum mechanics (RQM) were fraught with difficulty. Eventually it was realised that an extension of QFT provided a way of sidestepping the problems of RQM. In this extended version QFT became the natural language used by physicists to describe the relativistic behaviour of particles as well as what were traditionally regarded as fields. The spectacular growth and increasing sophistication of QFT’s methods also made it an increasingly valuable tool in areas of statistical physics and condensed matter physics that involved many particles, even when relativistic effects were of no relevance.

The result of this decades-long development is that QFT, is now seen as a general language for describing and analysing a range of physical problems, particularly in particle physics but also in condensed matter physics and many body theory. It is an important part of the toolkit of modern physics and as such is included in the training provided to a very large number of postgraduate physics students. Its importance is such that it merits inclusion in undergraduate programmes but its technical difficulty is so great that it often receives little more than lip service at that level, and sometimes not even that.

First steps in the teaching of QFT

In the teaching of QFT it is usually assumed that students are familiar with QM and SR. After short reviews of those subjects, and possibly some reminders of essential maths pre-requisites, there is often a brief discussion of RQM, typically listing its many successes but also emphasising its failures so that the need to introduce QFT as a general language is made clear. A well understood starting point is the non-relativistic Schrödinger equation of 1926

\[ i\hbar \frac{\partial}{\partial t} \psi(x,t) = \hat{H} \psi(x,t) \]  

(1.1)

Where \( \psi(x,t) \) is the (non-relativistic) wave function and \( \hat{H} \) is the (non-relativistic) Hamiltonian operator.

An early attempt to generalise this to a relativistic (i.e. Lorentz covariant) equation that could describe the quantum mechanics of spinless particles of mass \( m \) was the free Klein Gordon equation, also of 1926. (This had been considered and rejected by Schrödinger even before he proposed his own non-relativistic equation.)

\[ \left( \frac{1}{c^2} \frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} \right) \phi(x) = 0 \]

where the index \( \mu = 0, 1, 2, 3 \), the derivative operator, \( \partial_\mu = \left( \frac{\partial}{\partial x^0}, \frac{\partial}{\partial x^1}, \frac{\partial}{\partial x^2}, \frac{\partial}{\partial x^3} \right) \) and the \( x \) in the argument of the Lorentz scalar relativistic wavefunction \( \phi(x) \) represents the four position of an event in Minkowski space-time with coordinates \( x^\mu = (x^0, x^1, x^2, x^3) = (ct, x, y, z) \). Note that \( c \) represents the speed of light in a vacuum, while the construct \( \partial_\mu \partial^\mu \) uses the Einstein summation convention (summing over raised and lowered occurrences of the same index) as a convenient shorthand for the differential operator

\[ \sum_{\mu=0}^3 \partial_\mu \partial^\mu = \sum_{\mu=0}^3 \sum_{\nu=0}^3 \eta^{\mu\nu} \partial_\mu \partial_\nu = \frac{1}{c^2} \left( \frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2} \right) \]

where the index raising quantity \( \eta^{\mu\nu} \) with signature \((1, -1, -1, -1)\) is the Minkowski metric.

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An important step in the development of quantum physics was the recognition that in order to describe electrons and other spin ½ particles in relativistic quantum mechanics it was necessary to introduce four-component (column spinor) wave functions, as in the free Dirac equation of 1928

\[
(i\hbar \gamma^\mu \partial_\mu - mc) \psi(x) = 0
\]

where the Einstein summation convention has again been used, and the components of \(\gamma^\mu\) are four \(4 \times 4\) matrices that jointly generate a representation of the Clifford algebra \(\mathcal{C}L_{1,3}(\mathbb{R})\). Note that for reasons of consistency, the quantity \(mc\) in the Dirac equation is implicitly multiplied by a \(4 \times 4\) unit matrix \(I\). Also note that in what follows we shall generally (and usually without comment) use units in which \(c = 1\), and sometimes units in which \(\hbar = 1\) too.

The wave function based approach to quantum physics is superficially well suited to describe systems consisting of one particle interacting with an external agency (such as a classical field). It eventually encounters problems, especially if the relativistic creation of particles is considered but it can be used to provide useful information about many systems, including the relativistic corrections to the hydrogen spectrum. Almost inevitably though, most post graduate students need to be informed about quantum field theory itself.

**Approaching quantum fields**

As mentioned earlier, quantum fields were originally introduced to describe the quantum behaviour of quantities that were already regarded as fields, notably the radiation field. In 1926, Born, Heisenberg and Jordan in their celebrated ‘Dreimannen werk’ (see van der Waerden 1968) treated a 1-d field \(u(x,t)\) confined to a box of length \(L\) as a string with the classical (non-relativistic) Hamiltonian.

\[
H = \frac{1}{2} \int_0^L \left( \left( \frac{\partial u}{\partial t} \right)^2 + c^2 \left( \frac{\partial u}{\partial x} \right)^2 \right) dx
\]

They expanded the field in Fourier components with a time-dependent amplitude \(q_k(t)\), so

\[
u = \sum_{k=1}^{\infty} q_k(t) \sin \left( \frac{\omega_k x}{c} \right)
\]

where \(\omega_k = \frac{k\pi c}{L}\)

Thus they obtained a Hamiltonian for the field that looked like a superposition of harmonic oscillators

\[
H = \frac{L}{4} \sum_{k=1}^{\infty} \left\{ \dot{q}_k^2(t) + \omega_k^2 q_k^2(t) \right\}
\]

However crude the approximation, this they could quantize.
The quantum harmonic oscillator

Despite its vintage, the harmonic approximation is still fundamental to QFT, so a short review is included here. (More detailed treatments may be found in many places, the approach here is based on that in Chapter 5 of (Bolton and Lambourne 2007).) To treat the harmonic oscillator in non-relativistic quantum mechanics, starting from the Hamiltonian

$$\hat{H} = \frac{\hat{p}^2}{2m} + \frac{1}{2} \omega_0 m \hat{q}^2$$

the first step is to introduce the raising and lowering operators

$$\hat{A}^+ = \frac{1}{\sqrt{2}} \left( \frac{\hat{q}}{a} - i \frac{a}{\hbar} \hat{p} \right) \quad \text{and} \quad \hat{A} = \frac{1}{\sqrt{2}} \left( \frac{\hat{q}}{a} + i \frac{a}{\hbar} \hat{p} \right) \quad \text{where} \quad a = \sqrt{\frac{\hbar}{m \omega_0}}.$$

The Hamiltonian may then be written

$$\hat{H} = \left( \hat{A}^+ \hat{A} + \frac{1}{2} \right) \hbar \omega_0 \quad \text{with the commutation relation} \quad [\hat{A}, \hat{A}^+] = 1.$$

This may be used to show that the eigenstates of the quantum harmonic oscillator are

$$\psi_n = \frac{1}{\sqrt{n!}} \hat{A}^n \psi_{n-1} \quad \left( \text{with} \quad \psi_0 = \left( \frac{1}{\sqrt{\pi a}} \right)^{1/2} e^{-q^2/2a^2} \right)$$

with energy eigenvalues

$$E_n = \left( n + \frac{1}{2} \right) \hbar \omega_0$$

-where $n$ is a non-negative integer and

$$E_0 = \frac{\hbar \omega_0}{2}$$

is called the zero point energy.

Applying these results to the field Hamiltonian obtained above provided the earliest insights into the treatment of quantum fields but much more remained to be done.
**Canonical QFT**

By 1929 Heisenberg and Pauli had essentially formulated the canonical approach to QFT that is still used today (though alternatives are now available, as discussed later). For a real scalar field $\phi$, define the classical action by

$$S = \int d^4x \mathcal{L}$$

Where the classical Lagrangian density is

$$\mathcal{L} = -\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m^2 \phi^2 + \Omega_0.$$  

Impose the action principle

$$\delta S = 0$$

and use the resulting Euler-Lagrange equations to obtain the classical equation of motion

$$\left(-\partial^2 + m^2\right)\phi = 0.$$  

This has the general (classical) solution

$$\phi(x) = \int \frac{d^3k}{(2\pi)^3 2\omega} \left[a(k)e^{ikx} + a^*(k)e^{-ikx}\right]$$  

where $kx = k \cdot x - \omega t$ and $\omega = \left(k^2 + m^2\right)^{1/2}$.

Now comes the key step from classical to quantum physics. To achieve this first introduce (classical) conjugate momentum defined by

$$\Pi(x) = \frac{\partial \mathcal{L}}{\partial \dot{\phi}}$$

where $\dot{\phi}$ indicates the time derivative of $\phi$. Then, let the field and its conjugate momentum become operators obeying the canonical commutation relations

$$[\phi(x,t), \phi(x',t)] = 0, \quad [\Pi(x,t), \Pi(x',t)] = 0, \quad [\phi(x,t), \Pi(x',t)] = i\delta^3(x-x').$$

Consistency now demands that the coefficients $a(k)$ and $a^*(k)$ in the mode expansion of the field $\phi$ should also be treated as operators. Using the reinterpreted mode expansion to replace the fields and conjugate momenta in the commutation relations soon shows that the coefficient operators $a(k)$ and $a^*(k)$ satisfy the algebra of annihilation and creation operators for spin 0 (scalar) particles. The conclusion is that, subject to appropriate normalization requirements, and assuming the existence of a unique vacuum state $|0\rangle$, the state $a^*(k)|0\rangle$ represents the quantum state of a single free particle characterised by momentum $k$ and energy $\omega$ (treating $\hbar = c = 1$). Thus, our theory of free quantum fields has become a theory of free (quantum) particles.

The quantization of free complex scalar fields (introducing antiparticles), spinor fields (involving anti-commutation relations rather than commutators) and spin 1 gauge fields (starting with global gauge invariance) can all be considered in a similar way, though each adds significantly to the technical complexity of QFT and hence to the leaning load placed on the students.
Interacting fields

Of course, field theory becomes really interesting when the fields interact. An example of a simple (by the standards of QFT) interacting theory has

$$ S = \int d^4 x \, \mathcal{L} $$

and

$$ \mathcal{L} = -\frac{1}{2} \partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m^2 \phi^2 + \frac{1}{6} g \phi^3 $$

(1.9)

with the new final term representing a so-called “φ-cubed” self-interaction within the field.

The classical equation of motion for this theory is

$$ (-\partial^2 + m^2) \phi = \frac{1}{2} g \phi^3. $$

The route to quantization is now considerably more complicated. Some texts that give the full details will be discussed later. For present purposes it is sufficient to note that in the canonical approach perturbation theory is strongly emphasised from the outset, and the main target becomes the perturbative evaluation of scattering amplitudes (i.e. elements of the theory’s S-matrix) that can be used to compute scattering cross-sections and decay rates. In more realistic theories these latter quantities are, in principle, experimentally measurable and thus provide a potential test of the theory and its calculational methodology.

The required calculations make use of the interaction representation in which the time dependence arising from the interaction term is separated from that of the free (i.e non-interacting) theory. This has the effect of introducing a factor that represents the exponential of the interaction term, and it is the expansion of this as a power series in the constant g that is the source of the perturbation series. In the detailed calculation, attention becomes focussed on vacuum expectation values of time-ordered products of field operators, such as $\langle 0 | T [ \phi(w) \phi(x) \phi(y) \phi(z)] | 0 \rangle$, which are known as Green’s functions. These are the key to the evaluation of the scattering matrix elements that are being sought. Particularly important are the vacuum expectation values known as propagators (or two point Green’s functions) that involve the time ordered product of just two field operators. It turns out that, at a given order of perturbation theory, an arbitrary Green’s function can be expanded in terms of products of propagators. This is the basis of Feynman’s diagrammatic calculus (in which propagators are represented by lines) that does so much to simplify the process of actually carrying out a perturbative calculation in QFT, and which is therefore another important part of what must be taught and learned.

As is well known, attempts to carry out perturbative calculations in QFT, particularly those that involve closed loops in the diagrammatic expansion, superficially lead to infinities. In realistic theories these divergences can be removed by a process called renormalization that absorbs them into factors that relate the measurable physical parameters such as masses and coupling constants to their ‘bare’ equivalents in the original theory. After years of debate the status of renormalization in QFT has undergone some changes in recent years and it is no longer felt that only renormalizable theories can be truly physically interesting. Nonetheless, students still need to be taught at least the elements of renormalization, adding yet more items to the already lengthy list of concepts and techniques found in a typical QFT course.
Path integral quantization

An alternative to the canonical route to quantization is the use of path integrals. This is generally vital when dealing with realistic modern theories such as quantum chromodynamics (QCD) or the Weinberg-Salam theory of weak interactions, both of which belong to the class of local gauge theories in which the Lagrangian density is required to be invariant under local phase transformations. Since they have to be introduced at some stage, some teachers of QFT prefer to use path integrals from the outset, perhaps starting with a generating functional of the form

\[ Z(J) = \langle 0 | 0 \rangle_J = \int \mathcal{D}\phi \ e^{i \int dx [\mathcal{L}_0 + \mathcal{L}_i + J\phi]} \]

where \( \phi \) is an element of integration over all field configurations, \( \mathcal{L}_0 \) is the Lagrangian density of a free theory, \( \mathcal{L}_i \) the interaction term (or terms) and \( J\phi \) a term indicating an interaction with an external source \( J \), introduced for formal reasons.

Practical calculations will again involve Green’s functions, though they may now be obtained as functional derivatives. In the case of the free theory (when \( g = 0 \), and the generating functional may be represented as \( Z_0(J) \))

\[ \langle 0 | T[\phi(x_1)\phi(x_2)] | 0 \rangle_J = \frac{1}{i} \frac{\delta}{\delta J(x_1)} \frac{1}{i} \frac{\delta}{\delta J(x_2)} Z_0(J) \bigg|_{J=0} \]

In the full interacting theory the exponential of the interaction term may again be expanded in a power series in \( g \) and practical calculations carried out order by order. However in this case the theory itself may be regarded as having meaning beyond its perturbative evaluation.

A typical QFT course

Many universities offer a QFT course. Often, though not always, it is part of a first year postgraduate training programme or a module at the Masters level. Here is what may be regarded as a typical course skeleton, in this case based on a course listing from the University of Oslo.

- Quantisation of free scalar, vector and Dirac fields.
- C-, P-, and T-symmetry. Lorentz symmetry.
- Noether’s theorem.
- Interacting fields for quantum electrodynamics (QED).
- Generalisation to non-abelian theories for electro-weak and strong interactions.
- Derivation of Feynman rules.
- Elements of renormalisation.

Here are the related learning outcomes.

- The students get an introduction to relativistic quantum field theory.
- In particular electroweak interactions between leptons and quarks, and strong interactions between quarks are studied.
- It is emphasised that the student should be able to perform calculations of typical scattering and decay processes.
The discussion provided earlier touched on many of these topics but deliberately played down the role of group theory and symmetry transformations. For many students, these too will be new and unfamiliar topics that have to be confronted and overcome while studying QFT.

**Texts for teaching QFT**

There are a number of standard introductory texts that are commonly used on QFT courses. A few of the most popular are listed below, together with their length in pages. These are texts generally regarded as having a strong pedagogical bias, and are therefore books that a student of QFT might be reasonably asked to buy. There are, of course, many other QFT books and their omission from this list is not in any way intended to be a criticism of them. (The relatively short book by Maggiore in the Oxford Masters Series is perhaps aimed more at students taking QFT in their final undergraduate year or as part of a Master’s programme and is thus somewhat different in scope from the longer and more comprehensive texts aimed at students expecting to carry out substantial calculations.)

- Srednicki, Mark (2007). Quantum Field Theory. Cambridge, UK; Cambridge. 641 pages

Some quotations from the early parts of some of these books give immediate insight into the views of their authors regarding the difficulty of QFT.

One might think a subject of such power and widespread application would be complex and difficult. In fact the central concepts and techniques of quantum field theory are quite simple and intuitive.

From (Peskin and Schroeder, 1995) page xi

The first edition of this book aimed to give an easily accessible introduction to QED and the unified theory of electromagnetic and weak interactions.

From (Mandl and Shaw, 2010) page xi

QFT has the reputation of being a subject that is hard to learn. The problem, I think, is not so much that its basic ingredients are difficult to master ... but rather that there are a lot of those ingredients.

From (Srednicki, 2007) page xii

It is interesting to contrast these authorial comments with the sort of comments made by students. Student views are, of course, enormously varied. However as an encapsulation of much anecdotal evidence I offer the following statement made by Bojan Tunguz in his on-line review of the book Quantum Field Theory Demystified.

When I was first trying to learn Quantum Field Theory (QFT), at the end of my college years and at the beginning of the graduate schools, the jump from the “regular” quantum mechanics seemed almost insurmountable. Even with a full year of graduate quantum mechanics, the kinds of concepts and calculations that are the staple of QFT seemed beyond anything that I had encountered in Physics before. Unfortunately to this day there aren’t many QFT textbooks that will give you the benefit of the doubt when first learning the subject. Most of them aim to be comprehensive, rather than pedagogical. Which is unfortunate because many of the basic concepts and results are not beyond the ability of a more motivated undergraduate to grasp.
From (Tunguz, 2008)

Though Tunguz is now a practicing theoretical physicist his words capture a feeling that is common amongst students of QFT of simply being overwhelmed by the quantity of new material that must be absorbed in a short space of time. They sense a gap between what they know and what they are expected to learn, and the textbooks don’t seem to bridge that gap (despite what their authors say or intend).

Principles and pre-requisites in the learning of QFT

Many QFT texts, including most of those listed above, make some effort to explain the reasons why their author’s have felt it appropriate to add yet another volume to the already substantial ‘teaching’ literature of QFT. A particularly clear example is that of Srednicki’s text, in which the author sets out three explicit pedagogical principles; briefly summarised they are

1. The logical development of basic concepts, giving the impression that QFT is “effortlessly clear and obvious.”

2. Illustration of basic concepts with the simplest examples, leading to the ordering of material in terms of spin 0, spin ½ and spin 1.

3. User friendliness, which the author mainly aims to deliver by dividing the text into very small parts, each explaining a single concept, idea or calculation. Additional aspects of user friendliness are provided by making each section as self-contained as possible, listing required prerequisites at the start of each section, and repeating previously introduced equations rather than requiring the reader to refer back to them in earlier parts of the book.

Others might interpret these principles quite differently, or add extra principles. Many feel that the presentation should start with some indication of the real applications of QFT so that there is a context for the learning. A great many would emphasise the importance of performing calculations as a vital part of the learning process. Srednicki himself stresses the value of finding someone else with whom to share the reading of the book, as well as the value of repeated reading. If it’s not clear after three readings, then read it a fourth time! Other authors may not be as explicit as Srednicki but there can be no doubting their good pedagogical intentions.

Srednicki is also very clear about the background knowledge required to study QFT. While admitting that his listing of background ideas is incomplete, he says that a reader will probably know enough about quantum mechanics, classical mechanics, relativity and electromagnetism if he or she can recognize and understand the following eight items.

\[
\frac{d\sigma}{d\Omega} = |f(\theta, \phi)|^2, \quad A(t) = e^{iHt/\hbar}Ae^{-iHt/\hbar},
\]
\[
a|n\rangle = \sqrt{n+1}|n+1\rangle, \quad J_x |j,m\rangle = \sqrt{j(j+1) - m(m+1)} |j,m+1\rangle,
\]
\[
H = p\hat{q} - L, \quad ct' = \gamma(ct - \beta x),
\]
\[
E = (p^2 + m^2c^2)^{1/2}, \quad \mathbf{E} = -\mathbf{A}/c - \nabla \phi.
\]

Many will regard this as a very short list for such a challenging field of study but the requirement that each item should be ‘understood’ as well as recognized indicates that the student must have some depth of background, not just breadth.
Why is quantum field theory hard?

A proposed common reason for learners finding a subject hard is a failure of information processing, often due to overload (Ashcroft 1994). Norman Reid and his students at the University of Glasgow have, over a long succession of theses and publications (see for example (Palmer and Reid, 2003) and references therein), stressed the role that working memory and its limitations can play in science learning. They have made particular use of a model developed originally for chemistry education in (Johnstone, 1995). It has long been known (see (Miller, 1956) though there are also several later commentators quoted by Palmer and Reid) that working memory fails when required to deal with more that about 7 chunks of information at once. The descriptions of learning failures that emerge from these lines of research seem to be consistent with the comments of learners and even to some extent with the perceptions of Srednicki (quoted earlier) and other experts.

Those who advocate a failure of information processing and more specifically a failure of working memory as an explanation of student difficulty in QFT can also see it as providing an account of the experts’ belief that the subject is straightforward and perhaps even ‘easy’. According to the ‘7 chunk’ theory, what makes learning possible is the learner’s ability to redefine what constitutes a ‘chunk’ as familiarity with a subject grows. To a novice, ‘replace the function \(a\) by the operator \(\hat{a}\)’ may be a chunk. To an expert, the chunk could be ‘impose canonical commutation relations’ or even a much grander procedure, such as ‘apply the quantization method of a real scalar field’.

Conclusions, implications for teaching and lines of future research

The main conclusion of this paper is the obvious one that more research should be done on the pedagogical challenges of quantum field theory. Most of this paper has been devoted to simply showing the range of material and the sorts of concepts that must be studied. This is already a substantial undertaking because the subject is vast and the level of technical demand very high. A specific proposal has been made that might explain the origin of the learning challenge clearly perceived by students but seemingly invisible to many experts. However, this is only an initial proposal and certainly needs more empirical support or better still the challenge of competing proposals. The aim has been to provoke and promote further work, not to discourage it.

If the difficulty of QFT really is a result of working memory overload, then the analysis might suggest solutions or at least partial solutions that might improve effective learning. For example, students of QFT are required to work with many conventions simultaneously; the Einstein summation convention, state normalizations, Fourier normalizations, the use of natural units etc. These impositions could be removed or explicitly indicated. The resulting equations would be longer, but might be easier to interpret correctly if working memory capacity is a key problem.

More importantly, teachers of QFT should be aware of the learning limitations that arise from chunking and should try to arrange presentations, exercises and even their choice of textbooks so that students are encouraged to develop sensible ways of chunking the material as part of their learning. This might also have consequences for the writing of future QFT textbooks. For instance, Srednicki clearly perceives the need to present material in short self-contained sections, yet the contents page of Part 1 (Spin 0) of his text simply lists the titles of 32 such sections (there are another 21 in Part 2, and 44 in Part 3), far too many to be comfortably handled in working memory. His book is explicitly intended to be student friendly but perhaps its effectiveness could be improved by the simple step of grouping the contents of Part 1 so that the 32 original sections form 5 or 6 (new) Sections each of which contains 4 to 6 Subsections.

A similar approach could be applied to the detailed structure of texts, whether by Srednicki or any other author. A key step in this process would be the identification and flagging of individual concepts so that students and teachers were aware of what might be regarded as a minimal ‘chunk’ for the truly novice learner of QFT. Many books already do this, typically using boldface type to identify each new concept, yet it is not common in QFT and is not a feature of any of the 5 texts listed earlier. Even amongst authors who do try to give clear indications of new concepts, there does not appear to be any sign that the information is being systematically used to encourage the kind of chunking that might promote learning.
Clearly the working memory analysis suggests many possible lines of research, including a complete conceptual analysis of the subject. A totally different area of potential investigation concerns the activation of student learning. Standard textbooks have been emphasised in the paper because there is little else in many QFT courses apart from work on end chapter problems or similar calculational exercises. This does not have to be the case. There is no obvious reason why the techniques of investigation, analysis and treatment that have already been applied successfully elsewhere in educational physics cannot also be applied to QFT. It is to be hoped that this will happen and that the teaching of this important part of physics will benefit as a result.

References


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Recent Professional Development Programs for Practicing Physics Teachers in Armenia: Are They in Line with International Trends?

Julietta Mirzoyan, Science education research department, National Institute of Education of the Ministry of Education and Science, Armenia

Abstract

In Armenia, the reform of the national school education system goes along with intensive knowledge transfer and borrowings from abroad. This paper reports a study which examined two physics teacher professional development programs developed within the World Bank financed Education Quality and Relevance Project (2004-2014). Its objective was to evaluate two in-service physics teacher training courses, created in 2007 and 2011, in the context of the Western developments in science and physics education. The study attempted to answer the following main research question: have these courses the potential to change physics teachers’ views on teaching and learning and, consequently, the learning environment of their physics classes in accordance with the Western developments in science education? The courses were described and analyzed using a framework comprising main recent developments in science education research and practice in Europe and internationally. The study showed that although the two in-service physics teacher training courses include some information on Western educational approaches, they both suffer from insufficient theoretical underpinning and from a lack of exemplary physics subject specific teaching and learning materials, comparable with those developed in the Western countries; their potential to facilitate change of physics instruction in the Armenian schools in accordance with the European and international trends in science education is negligible. I hope this paper will provide a stimulus for discussion on mechanisms of educational knowledge transfer to post-Soviet countries from the West taking into consideration the fact that these countries are in a process of transformation of huge and well-developed systems of general education with firmly established traditions and culture in school science subjects instruction.

Introduction

Since the late 1990s Armenia has been transforming the national system of general education to make it relevant to new realities of post-Soviet era of the country’s history. Besides, in 2005 Armenia became a member of the Bologna process and the need to align educational standards at all levels of education with the European standards also came into national education policy agenda. The educational transformation processes have been taking place under a strong influence of some international donor agencies and numerous Western governmental and non-governmental organizations. Thus, it is clear that our reforms of the national school education system go along with intensive educational knowledge transfer and borrowings from abroad.

To what extent the Western and, particularly, the European developments in science education research and practice have been influencing the reform of school physics education in Armenia? To answer this question I launched a research program “Western innovations in science education research, development and practice and their influence on school physics education reform in post-Soviet Armenia” at the beginning of the 2000s. Continuous study of the European and international developments in science education through reviews of scientific and methodological literature in English, membership in the GIREP as well as participation in international science and physics education conferences held in European universities and scientific visits to the European internationally renowned centers for science education have given me the possibility to understand Western developments in science education.
It should be noted, that among many international organizations which have been implementing educational programs in Armenia, undoubtedly, the World Bank (the WB) became a leading donor agency in the school education sector and the only international organization involved in the general education reform at the country level. For this reason my research program have been mainly concentrated on the study of the developments in physics education within the WB’s financed reform projects.

The first WB’s operation in the country’s education sector was the Education Financing and Management Reform (the EFMR) project implemented in 1998-2003. Within the framework of this project the first generation of the Armenian physics curriculum materials, including standards, syllabi and textbooks were developed. The second WB’s operation is a 10-year Education Quality and Relevance Project (the EQRP) which is divided into two phases of five years duration each. The first phase of the EQRP was carried out in 2004-2009. The implementation of the second EQRP is now underway and will be finished in 2014. The main objectives of the first EQRP were: the development of the National Curriculum Framework (the NCF) and the State Standard for Secondary Education (the SSSE); subject standards and syllabi; introduction of student-centered teaching and learning methodologies and a new system of students’ assessment; integration of the ICT into instruction; and teacher professional development. The second EQRP has an objective to enhance further the quality of general education. Quality improvement through the realization of a new teacher professional development program is among the main strategies of the second EQRP.

Within my research program the following has already been done:

- Evaluation of the issues of nature of science, its philosophy and history in Armenian school physics curriculum. The results of this study were reported at the GIREP 2003 International Seminar and at the IHST Fifth International Conference in 2005.
- Two studies of the physics curriculum materials developed within the EFMR and the first EQRP. The results of the first study were published in a paper ([Mirzoyan, Gazaryan, 2004]; the results of the second one were presented at the GIREP 2008 International Conference.
- Evaluation of the influence of the general education reform on Armenian students’ science achievements assessed by TIMSS 2003 and TIMSS 2007. The results of this part of the research program were reported at the GIREP 2011 International Conference.
- A number of reports on these issues were prepared and presented to leaderships of the Ministry of education and science and the National institute of education. Several articles were published in the county’s pedagogical periodicals.
- The present study is an integral part of my research program. Its main objective is to evaluate two in-service physics teacher professional development programs of the first and second EQRP in the context of Western developments in science and physics education. The main parts of these two programs are in-service training courses, which were developed in 2007 and 2011. This paper presents an evaluation of these courses.

**Research questions:**

- What are the main developments in science education policy, research and practice in Europe and internationally?
- What are the aims of the two courses?
- Who are their developers?
- What physics teachers are expected to learn?
- What instructional methodology is suggested for these courses?
- Is there consistency between them?
- What international and European developments in science education are included in these courses? Are they presented in sufficient scope and depth?
• Have these courses the potential to change physics teachers’ views on teaching and learning and, consequently, the learning environment of their physics classes in accordance with the European developments in science education?

Research methodology:
• Review of European and international science education policy, research, and methodological literature;
• Study of the Armenian general education reform documents;
• Review of available evaluation studies on the general education reform outcomes;
• Description and analysis of the two courses.

It should be noted, that the entire field of school science education reform in post-Soviet era in Armenia was not studied by any other researcher – neither local, nor from abroad. There are only a few studies examining some general, cross-curricula aspects of school education reforms in the country (Hovhannisyan, A., Sahlberg, P. (2008); National Human Development Report 2006. (2007); Institute for Political and Sociological Consulting. (2011); International Center for Human Development. (2008); Terzian, S.M. (2010)). External evaluation studies were not conducted even for the WB’s first EQRP. The Implementation Completion Report on the first EQRP underlines that “… the absence of external evaluation studies makes it impossible to determine to what extent the Project has achieved its key indicator – 70 percent of teachers are engaged in activities likely to develop necessary knowledge and competences in their students.” (The World Bank, 2010, p.4).

The study’s conceptual framework: main European and international developments in science education

Many profound developments have been taken place in the field of science and particularly in physics education in Europe and around the world in the last 3-4 decades. There are many overviews of these developments (Benrendt, H., Danke, H., Duit, R. et. all. (Eds.), (2001); Eurydice. (2011); Jorde, D., Dillon, J. (Eds.). (2012); Mikelskis-Seifert, S., Ringelband, U., Bruckmann, R.M. (Eds.), (2008); Osborn, J., Dillon, J. (2008); Pilot, A. (2000); etc.).

Since the 1980s, the constructivist educational theory with its emphasis on students learning has gradually became a major theory in the field of science education. Conceptual change theory developed within the individual constructivist educational theory and later many other theories created on the basis of sociocultural approaches allowed a deeper understanding of students learning in science. Much research was done to study students’ misconceptions in science and especially in physics courses.

Throughout Europe and other parts of the developed world the achievement of scientific literacy for all students became a major aim of school science education. Students’ science competences are considered as principal outcomes of learning in science.

In accordance with these changes, significant transformations have taken place in curriculum development, teaching and learning methodologies as well as in assessment. In the EU, inquiry- based teaching and learning in science subjects is becoming a major pedagogical approach in recent years (European Commission, 2007). Teaching and learning in context (environmental, socioeconomic, technological, historical and philosophical) as an alternative to traditional science curriculum with its emphasis on the structure of the discipline is also gaining ground. Problem- and project –based learning, case studies create new possibilities for subject specific conceptual understanding as well as for development students’ cross-curricular knowledge and skills. The theory and practice of cooperative education has been attracting much attention among educational researchers and teachers. During the same period, unprecedented interest in science education research and to a lesser degree in classroom practice has been shown to issues of nature of science and science process skills such as modeling and argumentation. To be rated as a high quality, contemporary physics lesson should show physics as a dynamic system of knowledge and a specific methodology for its continuous construction and reconstruction.
Application of contemporary information and communication technologies (ICT) in teaching and learning science subjects creates new possibilities in shaping the classroom environment to enhance students learning in constructing their knowledge and understanding of scientific concepts, ideas, and nature and methodology of science.

All these developments which are taking place in science education research area and in many classrooms across Europe and in other countries of the world demand a profound modifications of the concept “teacher professionalism” and call for adequate changes in teacher pre- and in-service education and training. Teacher professional development became an important area of educational policy and research. In Europe, considerable attention is devoted to science teacher professional development at international, national and local levels. Many projects funded by the European Commission has been implemented to disseminate widely across European countries new teaching and learning methodology of inquiry-based science education and use of ICT in science classrooms through in-service teacher training. The development of high quality instructional materials is at the core of these projects.

Are these main European and international developments reflected in the two in-service training courses for physics teachers in Armenia?

In-service physics teacher training course, developed within the first EQRP: description and analysis

Description

First, this study has examined the materials developed in 2007 for a 5-day in-service training course of physics teachers (the first course) within the first EQRP. This particular course was chosen for this study because it is the only course developed within the first EQRP which was mandatory taken by the county’s all physics teachers. Trainers for this course were competitively selected mainly among physics educators from the National institute of education (the NIE) and physics teachers working in 52 School-Centers (SC). These SC were created in 2004 for introduction of school-based teacher training, development of new teaching and learning resources and dissemination of educational innovations all over the country. It should be noted that during 2004-2006 with the assistance of international experts 300 teachers from the SC were trained in cooperative learning methods with an aim to disseminate them in all Armenian schools. P. Sahlberg, the academic adviser to the authors of a handbook on cooperative learning published in Armenia, writes: “Armenia is doing something that has been rarely seen in the world. The entire education system is about to learn to use small group learning methods as essential element of teaching for knowledge society and better future.” (Hovhannisyan, A., Harutyunyan, K., 2006, p. 6).

A small number of trainers were prepared as the central trainers by international experts in 2006. The central trainers then worked with the remaining trainers. The county’s all physics teachers, more than 2000, were trained during 2007 by these trainers. It should be noted that all training sessions for local trainers conducted by international experts were not subject specific. It was believed that the trainees would be able to translate general pedagogical approaches into subject specific didactical knowledge themselves. On the contrary, the training courses for teachers conducted by local trainers within the EQRP were subject specific.

The first course does not have a syllabus. A single resource developed for this course is a handbook entitled: “Physics. Plan and materials for a 5-day teacher training (National curriculum framework, standards, syllabi, instructional materials and new methods)”. The handbook has four authors. Contributions to this handbook made by each of the authors are not specified. Two of the authors are former physicists, who stopped practicing their profession in the first years of Independence and since then have been working as educators. The other two are school physics teachers. The authors were selected from among the central trainers. During the post-Soviet period these authors were participants of many local training programs delivered by different organizations such as UNICEF, OSI, IREX and others. Thus, despite the fact that the handbook was developed within the first EQRP, it can be considered as an aggregate outcome of many educational projects carried out by foreign organizations in Armenia. The handbook was developed under the direct assistance of two international experts whose educational background and institutional affiliations are not specified by the authors. It has about 110 pages and is intended for both trainers and teachers.
It is necessary to note that in their address to the users of the handbook the authors did not write a word about physics and physics education reform in Armenia and elsewhere in the world. Nothing about teaching and learning physics can be found in their address.

The first four pages of the handbook present the course plan (outline) in two formats- short one and more extended one. The next 80 pages are the reprints of some parts of the NCF and the SSSE and a full reprint of secondary physics standards and syllabi for all grades from 7th to 12th. The handbook contains only 22 pages of methodological materials, which are presented in six sections under the following headings: 1) instructional methods – 12pages.; 2) methods of scientific cognition- 2pages.; 3) 3E learning cycle -2pages; 4) Types of lessons- 2.5 pages; 5) instructional resources- 0.5 pages.; 6) lesson planning- 3 pages. The decisive feature of these materials is that they are mainly descriptions of some general pedagogical approaches and very broadly defined algorithms for their applications. Physics subject specific methodological materials are almost fully missing in this handbook. The handbook does not include any information about expected outcomes of the course and how they should be evaluated. The text on methodological issues does not include references and it is impossible to determine sources of information provided in the text. At the end of the book a list of used literature is provided. None of the 15 sources of this list is from a field of science or physics education research and practice.

Of 22 pages of methodological materials more than a half, are devoted to the section “Instructional methods”. Each of the remaining five sections consists in average of only two pages. This circumstance makes their description and analysis senseless. That is why I will focus on the section “Instructional methods”. After a very short introduction to this section about passive, active and interactive methods comprising 1.5p., the authors present 13 “new methods”: brainstorming, two tables - T- and M- forms, concept map, Venn diagram and six other graphic organizers – one table and five flowcharts; the cooperative learning technique called “snowball”, an excursion and “project method”.

The resource does not contain suggestions for instructional methodology for this course. However, from the course’s plan one can very easily recognize that It is very simple. Trainers should give short lectures or talks, and then teachers have to work in small groups to perform different activities. The activities constitute a “backbone” of the course. The plan foresees 12 activities for trainees. It is clear that almost all of the instructional time is planned to spend on activities. I would like to underline the fact that the handbook is the only resource for trainers and trainees of this course. No other instructional materials, printed or electronic, no any technological devices (computers, projectors, etc.), or laboratory equipment are planned for usage during the training.

Analysis

The course is the first attempt made in Armenia in post-Soviet period to create a contemporary physics methods course for in-service teachers. The influence of Western pedagogical approaches on its content is an undeniable fact. In the handbook one can find such concepts as standards, student- and teacher-centered education, cooperative learning, active teaching and learning methods. The handbook also gives general information about some graphical forms of knowledge representation and analysis. It includes information on project work, 3E learning cycle and students’ investigations.

The main shortcoming of the course is that information presented in its main methodological part, which is very small, does not constitute a coherent set of pedagogical ideas, concepts and related methodological approaches. The sections of the methodological part of the handbook are not logically connected - they are discrete and isolated from each other. This is mainly because the handbook does not make clear for its intended audience the theoretical foundations of the “new methods”. Such concepts as scientific literacy, scientific competences, educational constructivism, students’ alternative conceptions, theory of conceptual change, theory of educational reconstruction, theories of situated learning, and sociocultural perspectives in science education, inquiry-based science education, context-based instruction and assessment, etc., do not find their place in the handbook. Thus, the theoretical input into this subject specific in-service training course for physics teachers is almost completely absent.
It would be very useful for Armenian physics teachers, for example, to know about numerous students’ and teachers’ misconceptions regarding basic physics ideas, concepts and nature of science so intensively investigated and documented in Western physics education research literature. Unfortunately, this strand of research and its results remains unknown for the country’s physics teachers and educators.

Thus, despite some contemporary general educational approaches and techniques reached Armenia and were presented in the handbook, they, in fact, are extremely insufficient for understanding the main European developments in school science and education.

Almost the full absence of physics subject related methodological materials is another shortcoming of this course. The handbook does not include exemplary physics instructional materials (lesson plans, different learning activities for students illustrating new methodological approaches, examples of students’ project works and investigations, etc.) because such type of materials simply do not exist in Armenia. And this is despite the fact that for more than a ten-year period prior to 2007, thousands of the Armenian teachers including physics teachers were trained within different education programs of numerous international organizations including the WB and a large pool of local trainers in contemporary teaching and learning methodologies was created. Even 52 SC created with an intention to develop, pilot and disseminate new type of instructional materials were unable to carry out their duties. That is why it is not accidentally that the list of literature used by the authors of the handbook does not include any physics subject related methodological resources. This shortcoming is first of all a consequence of the wrong assumption held by those who were responsible for the design of teacher training programs that physics teachers would be able to translate general pedagogical approaches and some general descriptions of their implementations into instructional materials for physics teaching and learning.

The course is actually activity-based and this is in accordance with contemporary vision for the teacher training in Europe and internationally. But the way these activities are planned in the handbook, unavoidably brings about doubts whether they can promote teachers’ understanding of the new general education policy, the NCF and physics curriculum materials, as well as the new pedagogical approaches. Of 12 activities 11 propose small groups of trainees to choose any theme from the new school physics syllabi and apply the information given in the certain part of the section “Instructional methods” in the context of the chosen theme. For example, in one of the activities small groups of teachers are required to choose by themselves any theme from the physics syllabi and using information about excursions provided in the handbook develop an excursion plan for their students. Then the groups should prepare posters and present their developed materials for discussions with other teachers. I would like to mention that there is only half a page information on excursion in the handbook. It is presented as an algorithm about the planning process of excursion consisting of 17 steps. Teachers are not provided with exemplary plans of excursion in their discipline or materials of any real excursion, organized within school physics curriculum in Armenia. Besides, it is obvious that the trainees would not have any possibility to collect the necessary information for doing this activity. I would like also to mention that of the five days of the training course half a day session is planned for this activity. It is obvious that such types of activities are a real waste of time and they cannot bring about any new understanding to teachers.

From the above it is obvious that the intention of the authors was to propose the use of instructional methodology based on cooperative learning approaches during the training sessions. For nationwide in-service training of teachers within the EQRP the following general strategy was envisioned: trainee teachers should be taught by methods they are expected to apply in their classrooms afterwards. And this is in full accordance with contemporary international approaches to teacher education and training. Now one can imagine what a physics lesson would look like and what its results would be if the type of cooperative learning, teachers are proposed to experience during the training, is performed in physics classrooms.

**Conclusion**

From the description and analysis of the first course it becomes clear that the volume and quality of instructional materials are insufficient to ensure the acquisition of new methodological knowledge by physics teachers and skills for using this knowledge to change the learning environment of their classes.
accoding to the European trends in science education. The finding of the evaluation study on the nationwide teacher training implemented within the first EQRP shows that many teachers use cooperative learning methods mechanically (Hovhanisyan, Shalberg, 2008). This is not a big surprise in the context of the analysis provided above. It should be noted that the researchers of this study were closely involved in the design and implementation of teacher PDP within the first EQRP and one of them is an international expert. The statement “It is a common view among many Armenian education specialists that mathematics and science teaching are among those where improvement of teaching is the most urgent” (Word Bank, 2009, p. 31) not a big surprise either in the same context.

The second in-service training course: description and analysis

Description

Shortcomings in teaching science subjects in secondary schools in resonance with the needs of a knowledge economy were defined as one of the key reform challenges that the PDP within the second EQRP aims to address (The World Bank, 2009). In 2011, a new 80-hour physics teacher in-service training course (the second course) was designed. As a developer for this course a physics teacher was selected, who was one of the authors of the first course. Since 2011 every year 20 percent of physics teachers were supposed to take this course with the goal to train all physics teachers by year 2015. Thus, the second course like the first one is envisioned for nationwide training of physics teachers.

The pack of materials developed for this course consists of a course syllabus and a Guideline for physics teacher trainers. The course syllabus consists of three distinct parts: 1) educational legislation (8hr); 2) ICT (12hr); 3) pedagogical and subject knowledge (60hr). The first two parts have the same content for 17 in-service training courses in all basic school disciplines designed within the second EQRP. The third part of these syllabi is subject-specific. The focus of my study is the third part of the syllabus of physics teachers’ training course and a relevant third part of the physics teacher trainers’ Guideline. It should be noted that all 17 in-service training courses were developed with the assistance of a foreign expert.

The third part of the syllabus does not have an introduction. Thus, the conceptual issues such as aims, instructional methodology, outcomes’ assessment strategies and instructional resources are not clarified. This part of the syllabus presents only themes to be studied and distribution of instructional hours among them. They are the following: 1) physics standards (2hr); 2) Methods of scientific cognition. Active learning methods (15 hr); 3) Study of physics concepts and phenomena (5hr); 4) Physics problem solving (10hr); 5) Demonstrations and experiments in physics teaching (10hr); 6) Types of lessons. Lessons planning (4hr); 7) Assessment (8hr); 8) Integrated lessons and multimedia (5hr); Wrap up (1hr). The title of the third part of the course does not correspond to its content. It seems that “Physics teaching in secondary school” could be a more suitable title than “Pedagogical and subject knowledge”.

The “Pedagogical and subject knowledge” part of the Guideline consists of about 100 pages of a text and a list of used literature. Like in the first course, there are not any references in it. But from the examination of the literature list and the content of the text it becomes clear that the text is mainly developed on the basis of Russian scientific-methodological literature on physics education published in Soviet and post-Soviet times. Of 14 literature sources of the list the seven are in Russian language and published in Russian Federation. Only five sources present literature in Armenian language. Of these sources three are curriculum documents (the NCF, the SSGE and the physics standards and syllabi) which already were studied by teachers during the first in-service training course in 2007. The fourth resource is a small-volume physics teacher manual to the new physics textbooks for 10-12 grades. The last resource in Armenian is a handbook prepared for the 3-day physics teacher in-service training course on assessment within the first EQRP. The list also includes two books published in the USA:


The Guideline’s units have identical structures. Each of them includes a text and some advices to trainers on how it should be studied. Like the first course, the second one is activity based.

Analysis

The analysis of the “Pedagogical and subject knowledge” part of the course in light of the present research agenda reveals that, as in the first course, an attempt to introduce some new Western methodological approaches to physics teaching and learning is evident in it. This is especially apparent in the section “Methods of scientific cognition. Active learning methods”. This section includes materials on physics models and modeling, project- and problem- based instruction, as well as some information on case studies. But like in the first course, this new information is not presented coherently and the theoretical background of new methodological approaches is not discussed.

The section about physics models and modeling does not discuss the role of models and modeling in students’ learning. It just gives some introductory information on the role of models in physics and the examples of well-known physics models which are included in Armenian school physics textbooks. In contemporary international research and methodological literature on physics education this theme has been attracting much attention in the last twenty years. The essence of this body of research and development is how to engage students in creating and revising models for sense-making and conceptual understanding and how to facilitate them to understand the possibilities and limitations of models and modeling process.

The analysis of the section on project works, problem solving and case studies in physics instruction also reveals that their contemporary meanings as teaching and learning strategies are not conveyed at all. According to research in problem based learning (PBL) “…students encounter and learn the central concepts of the discipline via the project” (Thomas, 2000, p.3). Projects that require the application of knowledge, not their construction and reconstruction, are not considered as examples of PBL. A study of the materials of the single student project given in this section of the Guideline shows that it is not a project in its contemporary meaning but a practical work with an objective of knowledge application. It should be noted that this material is taken from the Russian educational Internet resources.

The other sections of this part of the Guideline consist of materials which are mainly taken from Russian methodological literature on physics teaching.

Conclusion

Like the first course, the second one also includes some concepts from the contemporary approaches to science subjects teaching and learning. But in their scope and depth of presentation they are not sufficient to assist teachers to understand the international trends in science education. In contrast to the first course, the second course includes subject-specific methodological materials. However, these materials are mainly taken from the Russian methodological sources on physics teaching. Although a large number of local physics education experts in Western approaches to teaching and learning have been trained in Armenia and more than half a hundred of SC were established there is still a lack of methodological resources for in-service teacher training and classroom use in the country.

Concluding remarks

Although the two in-service physics teacher training courses developed within the first and second phases of the EQRP include some information on Western educational approaches, they both suffer from insufficient theoretical underpinning and from a lack of exemplary physics subject specific teaching and learning materials, comparable with those developed in the Western countries. Their potential to facilitate change of physics instruction in the Armenian schools in accordance with the European and international trends in science education is negligible.

The main reason for this is inadequate mechanism of educational knowledge transfer to Armenia from the Western World which was used in the WB’s and other educational projects. It was believed that a few educational experts from abroad would be able to prepare groups of local experts in contemporary
Western subject specific pedagogical theory and practice through workshops conducted on general pedagogical issues. In these workshops very small attention was paid to theoretical foundations of new teaching and learning strategies. The participants of these workshops were mainly school teachers and some teacher educators. As a rule, they did not hold scientific degree in educational sciences and were not proficient in English- the language of workshops. That is why it is not surprising that the efforts of local Armenian experts in physics education to develop physics teacher training courses reflecting the European and international trends in this area were mainly unsuccessful.

At present, the Armenian Ministry of education and science takes actions to change the situation with educational specialists. It is foreseen to educate new high level professionals in the field of pedagogical sciences within master and doctoral degree programs abroad. Besides, a very much delayed reform of Armenian state pedagogical universities aimed to make the national standards of teacher education consistent with the European standards is now underway. It should be noted that recently Armenia has become a very active member of the Bologna process and has made significant progress in reforming the field of higher education. Undoubtedly, these developments will positively influence the entire system of teacher professional development in the country.

The WB also makes changes in its educational policy. The new WB`s educational strategy 2020 (World Bank, 2011) proposes to create a high-quality knowledge base on education systems reforms at the global level. This will reduce the negative consequences of the reliance on the expertise of a few external professionals when reforming the entire system of education. The new strategy also foresees strengthening of attention to issues of the WB`s educational programs monitoring and impact evaluation. These measures are very timely and important also in the light of the evaluation results of the two physics teacher PDPs of the EQRp in Armenia.

References


Mentoring as a Form of Professional Support for South African Physics Teachers

Umesh Dewnarain Ramnarain, Department of Science and Technology education, University of Johannesburg, Johannesburg, South Africa
Sam Ramaila, Department of Physics, University of Johannesburg, Johannesburg, South Africa

Abstract

This study reports on mentoring as a form of professional support for Physical Sciences teachers in dealing with curriculum reforms associated with the implementation of a Physical Sciences curriculum. Using a case study method, we investigated two cases of mentoring. The first case explored a traditional mentoring relationship between a novice teacher and a more experienced and competent teacher whom we referred to as a “keystone species” of the profession. The second case described a more collaborative form of mentoring between two experienced teachers who exploited each others’ strengths in overcoming some of the deficiencies in their practice. The findings of the case study suggest that mentoring although complex does provide a viable means through which professional development efforts can be consolidated, and may be considered as an alternative to the cascade model of in-service training consisting of short one-shot workshops that assumes a ‘one size fits all’ approach.

Keywords: mentoring; keystones species; professional support

Introduction

A primary constraint in the implementation of a reformed Physical Science curriculum in South Africa has been the lack of professional development of teachers. The pivotal and central role of the teacher in curriculum implementation has been underlined by Bybee (1993) who maintains that if teachers do not in their practice represent the curriculum innovations, the entire process of curriculum change falters and eventually fails. Furthermore, he highlights the context-specificity of curriculum implementation in that “individual decisions are neither directly culturally universal nor policy-specific” but are “absolutely singular, applicable in one case and one case only” (p. 43).

Teachers in South Africa feel overwhelmed by the challenges presented by the reforms in the Physical Sciences curriculum. The two major reforms that are deemed to be most demanding are the new topics in the curriculum, and the investigative approach to practical work. Studies have revealed that teachers lack confidence in teaching some of the new topics in the curriculum (Kriek, 2005; Muwanga-Zake, 2004). At the same time, this has impacted on their pedagogical content knowledge (PCK) in relation to these new topics (Kriek & Grayson, 2005) by limiting their ability in translating subject content knowledge into useful forms of representations of ideas in the form of “powerful analogies, illustrations, examples, explanations and demonstrations” to facilitate comprehension by students (Shulman, 1986). The investigative approach to practical work is in stark contrast to the traditional ‘cookbook’ approach where learners follow ‘recipes’ for the execution of procedures handed down by the teacher without much thought (Kim & Tan, 2010). A concern here is that teachers lack expertise in facilitating learner-centred scientific investigations (Onwu & Stoffels, 2005).

Teachers have bemoaned the lack of substantive support from the Department of Education by expressing dissatisfaction with “the learning resources and the level of support they were given as well as the quality of training to which they were exposed” (Kriek & Basson, 2008, p. 73). Ono and Ferreira (2010) point out that the Department of Education introduced a “cascade” model through which teachers were trained and in turn had to pass their knowledge onto their colleagues. This resulted in crucial information being watering down or misinterpretation of crucial information. Such professional development efforts have been criticised by many researchers as being brief, fragmented, incoherent encounters that are de-contextualised and isolated from real classroom situations (Feiman-Nemser, 2001; Villegas-Reimers, 2003). Research has demonstrated that short-term and low-quality professional development experiences can be a barrier to the implementation of science education reform (Jeanpierre, Oberhauser & Freeman, 2005). In reflecting on the need for quality science teachers in South Africa, Parker (2009) cites the McKinsey Report...
(Barber & Mourshed, 2007) that investigated high-performing education systems in OECD countries. Two important findings of the study were that the quality of an education system cannot exceed the quality of its teachers, and the only way to improve learners’ performance is to improve instruction.

It is against this background that we embarked on a study in investigating the professional development of teachers as a sustained and collaborative effort (Loucks-Horsley, Hewson, Love & Stiles, 2003). We report on two cases of mentoring as a form of support for teachers, each case having its own distinctive features. The first case explored a traditional mentor-mentee relationship between a novice teacher and a more experienced and competent teacher whom we referred to as a “keystone species” of the profession. The second case described a more collaborative form of mentoring between two experienced teachers who exploited each others’ strengths in overcoming some of the deficiencies in their practice. We refer to this as a mentor-mentor relationship.

**Dimensions of mentoring**

Mentoring has increased in popularity as a way by which a teacher experiencing some weakness in his/her practice can be supported by a skilled and experienced colleague (Bradbury, 2010). Mentoring in teacher education involves complex personal interactions “conducted under different circumstances in different schools in which it cannot be rigidly defined” (Wildman, Maggliaro, Niles & Niles, 1992, p. 212). In this study we hoped to uncover some of this complexity by reporting on two distinctive cases of mentoring. Madison, Watson, and Knight (1994) as cited in Barrera, Braley and Slate (2008) provides characteristics of effective mentors which include: (a) a generosity of time; (b) a willingness to learn; (c) a complete trust; (d) an ability to praise and encourage; and (e) an openness to recognise the limitations of others. We were also keen to understand the extent to which these characteristics were reflected in the two cases studied.

According to Lai (2005) mentoring has been conceptualized with respect to its relational, developmental and contextual dimensions. The relational dimension of mentoring refers to the relationship between the mentor and the mentee. Developmental refers to how mentors and mentees develop personally and professionally whilst aiming towards particular goals. Contextual focuses on cultural and situational features of the mentoring setting and recognizes the powerful influence of the school organization and culture on teacher learning. Our research on the two cases of mentoring was framed by these dimensions.

The following research question was formulated:

How does mentoring enable Physical Sciences teachers overcome some of the challenges posed by curriculum reform?

**Methodology**

A qualitative case study design located in the interpretive tradition was employed, as we wanted to understand the nature, dynamics and complexity of mentoring at two schools. This method was considered appropriate as a case study design as it is used to gain an in-depth understanding of the situation (Cohen, Manion & Morrison, 2002).

The schools were both purposefully and conveniently selected. The schools were purposefully selected as they depicted cases where Physical Sciences teachers were involved in mentoring relationships. The two cases that are presented offer interesting insights into the nature of a mentoring relationship. The location of both schools was convenient as they were accessible to us in terms of travelling distance.

Data were collected through interviews with the teachers, listening to discussions between the teachers and classroom observations over a period of three months. The case study enabled us to gain an insight into the process of mentoring, and also the tensions and dynamics of the interaction between teachers. The data were analysed using the Atlas.ti software. We firstly did an open coding of the data by assigning codes to segments of the text. This was followed by axial coding whereby we put “the parts of the data identified and separated in open coding back together in new ways to make connections between categories or the codes” (Henning, Van Rensburg & Smit, 2004, p. 132). We were guided in this process by the dimensions of mentoring. We were able to group the codes into code families, which to a large extent corresponded with...
the dimensions. We sought to establish reliability in this process of coding and grouping codes into families by doing independently the coding. There was a 91% percentage of agreement between us in this process of data analysis. In this paper we will report on the themes which emerged as result of this analysis.

For each of the cases, I will profile the school, the two teachers, and then describe the mentoring relationship between the teachers in terms of its relational, developmental and contextual dimensions.

Findings

The case of a mentor-mentee relationship

Banato High School is a city school that is located in central Johannesburg, South Africa, and is described as a former model C school. In the Apartheid education system a model C school was designated for White children. The school is now racially integrated, with many Black children travelling from a neighbouring Black township. The school is adequately resourced for science with two laboratories that are being used. The school has 995 students. The pass rate for the Grade 12 national exit examination in the previous year was 83%. The school fee was R5000, with a 65% collection rate. The teachers were all employed by the state. The average class size is 35.

Mr Ndlovu has 15 years’ experience teaching Physical Sciences. He is well qualified and has a Bachelor of Science degree with Mathematics and Physics as his majors. He also has a Higher Diploma in Education. He is the subject head in Physical Sciences at the school. He teaches grade 11 and grade 12 Physical Sciences. The learners in his class have consistently produced good results in the national grade 12 examination. His expertise in the subject has also been recognised by his Department of Education subject facilitator who nominated him to act as examiner for a district examination in Physical Sciences. We regarded Mr Ndlovu a ‘keystone species’ in his profession.

Mr Ndlovu acted as a mentor to a novice teacher, Mr Ngidi who had graduated the previous year from a university in Johannesburg with a Bachelor of Education degree. His specialist teaching subjects are Physical Sciences and Mathematics. He teaches grade 9 Natural Sciences and grade 10 Physical Sciences. The relational, developmental and contextual dimensions in this case of mentoring are now discussed.

Relational dimension: The dynamic nature of a mentoring relationship that was built on trust and respect

Mr Ngidi described his relationship with Mr Ndlovu as one that was built on mutual trust and respect. He explained that Mr Ndlovu was always accessible to him when he needed support. The level of trust was reflected by him readily inviting Mr Ndlovu into his class without any reservations. Apart from trust, the mentoring relationship was sustained by a strong sense of caring from Mr Ndlovu.He was well aware of the high attrition of novice teachers and often spoke about how Mr Ngidi needed to be nurtured. This is underlined in the following excerpt.

I have fifteen years experience now teaching Physical Science and now I’ve got a relationship with a new teacher. He is the new blood, and it makes me excited when I think about myself being in this position. He is like a new plant that is still growing.

Both teachers reflected on the changes in the mentoring relationship over the year. It became apparent that the relationship was dynamic as there were changes in their roles as the relationship evolved. Over the first few months, there was much support from Mr Ngidi in the mentoring relationship. This was a critical period for Mr Ngidi as he was entrusted with taking charge of a class for first time. He was unable to maintain a disciplined learning environment in class, and learners often disrupted lessons. During this period he had almost daily discussions with Mr Ngidi whereby he solicited advice on how to deal with this issue. In this interaction he would describe what had unfolded in the classroom, and then Mr Ngidi would make suggestions on what could be done. Based on this advice he tried out different strategies. This level of support also extended to advice on curriculum issues. Over time, Mr Ndlovu indicated that the discussions became more engaging as he was now able to better reflective on the events in his classroom. With some prompting by Mr Ngidi he was able to generate his own ideas on how situations in his classroom should be
managed. The discussions were more interactive and he got a sense that the relationship was becoming more collaborative as often Mr Ndlovu would ask his advice on an idea he had for teaching a topic. The nature of this evolving relationship was described by Mr Ngidi as follows:

At first I depended a lot on Mr Ndlovu. I would say maybe he was my crutches. But this was starting to change as I could see my ability growing. He was starting to see me as somebody he could rely on.

It would appear that the degree of support from the mentor was fading as the mentee started to acquire more competence and confidence in his teaching.

**Developmental dimension: Defining the role of a facilitator and developing PCK**

Mr Ngidi admitted to feeling “a little overwhelmed” when first asked to teach Physical Sciences. He identified classroom management and his lack of pedagogical content knowledge as his major challenges. He recognised that an important principle of the new curriculum was learner-centredness, but had difficulty in managing class activities where learners are allowed more autonomy. This was especially the case when he gave learners the opportunity to do scientific investigations.

Through reflective discussions with Mr Ndlovu he was able to gain some insight into how to better manage practical activities by defining more clearly his role as facilitator during these activities. He came to understand that learner-centredness did not imply that learners “should be left to their own devices” but that they needed to be scaffolded by the teacher through the use of support strategies. As a result of this he was able to maintain better control of the class during these practical lessons and the activities led to meaningful learning experiences. He expressed this support from Mr Ndlovu as follows:

I came to understand my role better when I arranged practical activities for my learners. Many times they were lost and this would frustrate them and they then got up to mischief. From Mr Ndlovu I could see that there were strategies to help learners. For example I learnt that they needed to be prompted at certain times to make progress.

Mr Ngidi received mentoring in developing his pedagogical content knowledge. He recounted how initially he struggled to “connect with learners” as he was unable to make scientific knowledge accessible to them. Through mentoring he was able to understand how this scientific knowledge needed to be transformed so that learners were better able to relate to it better. He described this development follows:

I know I am confident with my content. I spend a lot of time going over the textbook. I tried to put it across to learners, but they struggled to understand it. In a discussion I had with Mr Ndlovu I started to see things were not straight forward. It is about making the learning easier for them by using what they already know and making it link to what I am teaching.

I was invited to one of the discussions whereby Mr Ndlovu supported Mr Ngidi in developing his PCK on the electric current in a circuit. Mr Ngidi had already introduced the topic to his grade 10 class, but realised that learners were not grasping how and why the electric current flowed in the circuit. In this lesson he had used shown learners a circuit board with a simple circuit connected, and then explained the flow of current using a circuit diagram. In the discussion I attended Mr Ndlovu explained to Mr Ngidi that the flow of current in a circuit was an abstract concept to learners as it was something they were unable grasp at a macroscopic level. He advised Mr Ngidi to use an analogy that would make the concept become more concrete to the learners. Mr Ndlovu suggested relating the flow of current to a water ride at a water park. The discussion then focussed on the common elements between the electric circuit and the water ride. Firstly, it was established that the electric current could be compared to water. Mr Ndlovu prompted Mr Ngidi on how he would need to make explicit the comparison between the electric current and water. He asked Mr Ngidi to identify all the characteristics of an electric current and to explain how these characteristics were shared with the water flowing in the slide. Apart from identifying the similarities between the electric circuit and the water ride, the teachers also explored possible difficulties in learner understanding which may arise as a result of this analogy. For example, Mr Ngidi raised a concern that the learners may relate the people on the slide to the electric charge moving through circuit. It was then decided that the analogy of the water ride should exclude people. By the end of the discussion, Mr Ngidi...
expressed confidence that he would be able to teach the lesson using the water ride analogy. The next day we accompanied Mr Ngidi into his grade 10 class. We observed that he effectively used the analogy to explain the concept of the electric current in the circuit. The learners were thoroughly engaged in the lesson and there was good interaction between Mr Ngidi and the learners, as well as amongst the learners.

In the post-lesson interview, Mr Ngidi described the idea of using the analogy as “a good way to help learners who struggle to see the light”. It was also evident from the learners’ responses to the test that they were able to correctly relate the science concept to the analogue, and hence acquire a better understanding of the concept. It was clear he had found the use of the analogy an effective strategy in making a science concept more accessible to his learners. He also recognised how the pre-lesson discussion he had Mr Ndlovu had pointed him “in the right direction”.

**Contextual dimension: A school culture that is conducive to mentoring**

Although the mentoring relationship had developed spontaneously, the management of the school did take steps to ensure the easy integration of new teachers into the school. For example, new teachers are generally given a lower teaching load in their first year to facilitate this transition. Mr Ndlovu referred to this when asked about the support for the management of the school for novice teachers.

> Here at the school we have got a policy of integrating the new teachers in the whole system. They need to learn quickly but we must create the environment to prosper. The principal knows the profession can turn you off in the first year and teachers can become frustrated.

When asked about the professional support from the Department of Education and its role in facilitating his mentoring, Mr Ngidi expressed his disappointment that the subject advisor had not established contact with him nor made any enquiries with the school about his developmental needs. He had on two occasions without success tried to set up meetings with his subject advisor so that he could be guided professionally. Furthermore, he stated that the Physical Sciences cluster meetings arranged by the subject advisor and involving teachers from ten neighbouring schools served primarily an administrative function, and did not provide the professional support he anticipated. Consequently, there was little opportunity for him to interact with teachers from other schools on issues related to classroom practice. This is evident from the following comment:

> I have the issue that my subject advisor is not here to guide me along. It is now almost a year and I still have to be visited. I have attended all the meetings, but we hardly ever talk about our experiences at teaching.

It can be inferred that the community of practice as experienced by Mr Ngidi is largely confined to his own school through his mentoring relationship with Mr Ndlovu. The mentoring relationship appears to be borne out of necessity due to his professional needs as a novice teacher and the lack of support from the Department of Education.

**The case of a mentor-mentor relationship**

Hopewell High School is located in a densely populated township. The area was previously designated a Black township under the Group Areas Act, which demarcated residential areas for race groups. The people in the township belong mainly to a low income group. There is a high rate of unemployment. The school has 960 Black students. The pass rate for the Grade 12 national exit examination in the previous year was 58%. The school fee was R400, with a 35% collection rate. The average class size is 42. The school is adequately resourced for practical work, and has one laboratory. The laboratory has sufficient apparatus and chemicals for the required practicals specified by the curriculum.

Both teachers involved in this relationship have good teaching experience, with Miss Skosana having taught Physical Sciences for 10 years and Mr Modiba with 9 years experience in the subject. Miss Skosana has a Bachelor of Arts degree and a Post Graduate Certificate in Education with Physical Sciences and Life Sciences as her specialist teaching subjects. Mr Modiba has a Bachelor of Science honours degree in Biochemistry and is currently pursuing a Masters’ degree in Education. Both teachers have been teaching at the school for the past three years. They appear to share a constructivist view on learning because they
subscribe to the notion that learners construct their knowledge actively rather than ingesting information
from their teacher or textbooks. They are both held in high regard for their commitment to their jobs. The
head of department for science described Miss Skosana as being “a caring mother who does everything
she can to uplift the learners”. He described Mr Modiba as “a role model to all teachers as he goes beyond
the call of duty at all times”. We now discuss the relational, developmental and contextual dimensions of
this relationship.

**Relational dimension: A mutually beneficial relationship where teachers exploit each others strengths in overcoming deficiencies in their practice**

The mentoring relationship for this case differentiates itself from the traditional mentor-mentee
relationship. We describe it as a mentor-mentor relationship as it is mutually beneficial to the teachers.

Both teachers described the reforms to the Physical Sciences curriculum as being “challenging” but believe
that they are able to cope as a result of the support they offer each other. They each have particular
strengths and are willing to offer professional support based on these strengths to the other.

They engaged in a collaborative working relationship whereby they planned lessons together. In essence
this was a “partnership” in which they shared a common interest in the pursuit of excellence in the classroom. There was an arrangement in place in which they set aside time to meet in the afternoons to
plan lessons. These discussions often took the form of brainstorming sessions in which they explored ideas
on how best to teach a topic. At the same time they resolved uncertainties they had in their conceptual
understanding.

As indicated below, the support with regard to the teaching of the new topics was also at an emotional
level. Mr Modiba commented that:

> We were very anxious in teaching about the new things. For the first time I started to feel tension.
> She felt the same way, but we got together and said that we will work together on it. It was very
> hard work now developing worksheets and planning lessons but we shared the work.

**Developmental dimension: Teachers exploit each others strengths in overcoming deficiencies in their practice**

Mr Modiba and Miss Skosana each have particular strengths as physical sciences teachers and it was
evident that they were each able to tap into other’s strength. Learner-centredness is one of the principles
that underpins the science curriculum. Miss Skosana’s teaching style was adept to this approach as her
teaching philosophy is that learners need to be “actively engaged so that science becomes meaningful to
them”. She therefore spent much time planning autonomous learner activities and this was considered a
strength Mr Modiba indicated that he believed that practical work has a “huge role to play in science”. As a
result he readily infused his lesson with the investigative approach. He was both competent and confident
in this approach, and we regarded this as a strength. Through mentoring the teachers exploit each others’
strengths. Mr Modiba referred to the learner activities that are designed by Miss Skosana and how he had
used some of these activities with his own learners. He explained this as follows:

> I think she’s been more resourceful especially in terms of classroom activities because she gets
> these books with worksheets and all that. So we tend to share all of that. So that everything that
> we do is mostly uniform.

Miss Skosana stated that she had benefitted greatly through her interactions with Mr Modiba. In particular
she spoke of her development in teaching lessons involving practical work. She indicated that at times she
questioned her competence at doing practical work. In her teacher training she had done little practical
work. The school where she previously taught was poorly resourced for practical work and hence she
did not do much practical work there. She explained how Mr Modiba took the trouble to guide her in
this regard and help her develop her experimental skills. Before a practical lesson took place, Mr Modiba
would show her how to set up the apparatus and conduct the experiment. Thereafter, she would do the
experiment on her own to become more confident. She described this support as follows:
When it comes to a practical lesson I used to be always tense, because I feared something would always go wrong. I needed to build up my confidence. Now I have the opportunity working with Mr Modiba to rehearse beforehand. He has been very patient in showing me what to do.

Contextual dimension: A community of practice confined to the school

When asked about why the community of practice did not involve teachers from other schools, they responded that they had made attempts to work with teachers at other schools but this did not work out. They had approached teachers at other schools with a view to collaborating on planning lessons, especially lessons where the new topics were taught. Meetings were arranged at their school and neighbouring schools. Initially, the meetings were fruitful as teachers shared ideas on how to teach the new topics. However, with time this collaboration fizzled out. Mr Modiba explained that the demanding duties at school meant teachers could not find the time to meet.

It looked very promising at the beginning of the year. I could feel the energy as we met our colleagues from other schools. Then all of a sudden it started to die. They would explain that they had to do sport or there was a test they had to mark for the next day.

Miss Skosana added that although she believed the lack of time was the main reason for the collaboration with teachers from surrounding schools having failed, she also got a sense that teachers lacked trust and confidence in sharing their ideas. She described this as follows:

And also sometimes you’re scared to share. You are scared that the other person is going to think it’s not good enough or whatever and you think it’s a good idea but you’re scared to be put out there and people to see your work.

Both teachers expressed a lack of confidence in the cluster meetings as a platform for collaboration. They contend that teachers are consumed by the demands of teaching and do not have the space to discuss and share ideas on their teaching.

Mr Modiba described the situation as follows:

We are so overwhelmed and you know that everytime we get together at cluster meetings you say you are overwhelmed. You say you must do something. We must share our papers. We must do something but we become so overwhelmed it’s like you are in survival mode. You just want to get this deadline.

Both teachers were critical of their subject advisor. They maintained that he was not a Physical Sciences specialist but was appointed to the position as a result of his “contacts”. His role as they described it was to check up on teachers to ensure their record-keeping was in order. In this regard they described him as being heavy handed and authoritarian. He handed assessment sheets and lesson plan grids and demanded that teachers comply as he instructed them to do so. When the teachers asked advice on curriculum issues they found their advisor to be deliberately evasive. At times he became antagonistic when challenged on professional issues. Their frustration at working with their subject advisor was aptly captured by Miss Skosana as follows:

He is an incompetent person who has not helped anybody in this circuit. He is like a police who is constantly checking on us like children. He has not taught science in his life. I heard he was a geography teacher and was promoted to this post because he is a buddy of the director.

When asked about how the management of their school viewed mentoring and the extent of support for it, they both indicated the management had not explicitly promoted, even for novice teachers. The school principal and their head of department were aware of the close working relationship between them but had not taken any steps to encourage collaboration amongst teachers.
Discussion

The findings of this study suggest that mentoring does provide a viable means through which professional development efforts can be consolidated. Much of the research referred to earlier focused on the roles of the mentor and mentee separately. This study has informed on the interconnectedness and meshing together of these roles. Furthermore, the dynamic nature of the mentoring relationship was revealed as the case of the mentor-mentee relationship as the roles changed as the relationship evolved. Initially the relationship was one-sided as the mentee had a strong dependency on the mentor in seeking advice on how to overcome the challenges he experienced in his teaching. With time the nature of the relationship shifted as the mentee with his increasing confidence and competence now started to engage with his mentor more collaboratively. The implication of this for mentoring as a form of professional development is the relationship cannot be static but should be dynamic. It was becoming evident to us that mentor-mentee (M-m) relationship involving Mr Ndlovu and Mr Ngidi was evolving into a form that was starting to resemble the collaborative mentor-mentor (M-M) relationship of Mr Modiba and Mrs Skosana. We represent this shift from a supportive to a collaborative relationship in Figure 1.

Figure 1. The dynamic nature of a mentoring relationship

It was also apparent that at any given stage in this relationship there was mutual trust, respect and care.

The findings with regard to the contextual dimension of mentoring suggest that a more concerted effort needs to be made in creating conditions that would facilitate a community of practice in which mentoring may thrive. In this regard subject facilitators need to be instrumental in initiating communities of practice so that teachers engage collaboratively on curriculum issue that are significant for the context in which they teach. They need to identify ‘keystone species’ who can act as mentors to colleagues who have professional development needs. The management of schools needs to support teachers within schools and across schools so that are able to establish communities of practice. Where possible formal arrangement needs to be made with ‘keystone species’ at other schools so that these teachers may provide support to teachers needing professional development on the curriculum.

In plotting the way forward it is recommended that further research be undertaken on mentoring in science education. The findings of this study have provoked further questions on mentoring that should be addressed in subsequent studies. These include: What level of support in a mentoring professional development is optimal? What type of impact does mentoring have on the classroom practice of teachers? What characteristics does a good mentor possess? What factors at school support mentoring relationships? What factors limit the success of mentoring relationships and what can be done to overcome them?

In addition, more case studies of mentoring across diverse settings that is synonymous with the South African education landscape would inform on the viability of mentoring as a widespread form of professional support for teachers.

WCPE 2012, Istanbul, Turkey
References


Proceedings of The World Conference on Physics Education 2012
Interactive Physics Laboratory and Collection of Demonstration Experiments

Zdeněk Šabatka, Zdeněk Drozd & Věra Koudelková, Charles University in Prague, Czech Republic.

Abstract

The Interactive Physics Laboratory is a laboratory where teachers are invited to come with their students to do mostly experiments with tools which are too expensive for regular high school or experiments which are in some way innovative and even teachers do not know them yet. IPL organizes also courses for teachers where they can go through the same experiments themselves and gain experience with them before coming with students. The Collection of demonstration experiments is an internet database which is dedicated mainly to physics teachers. The Collection of demonstration experiments was established within a project dedicated to improvement of a seminar which prepares future teachers for doing demonstration experiments. The main purpose of this paper is to inform about those activities for high school teachers and their students. We hope that they could inspire other activities somewhere else and lead to cooperation, exchange of experiences and good practice.

Keywords: Physics, demonstration experiments, laboratory experiments, secondary school, students, teachers, collection, Electricity and Magnetism

Interactive Physics Laboratory and Collection of Demonstration Experiments

Introduction

Practical work takes traditionally an important part in physics education. Students are being impressed by their teacher’s demonstrations, they do experiments (also laboratory ones), and once or twice a year they can take part in a school project. Students face experiments mainly in school thanks to their teachers.

To give Czech physics teachers further examples of experiments for their demonstrations and to augment students’ chances for doing experiments two projects were established: “Interactive physics laboratory” and “Collection of demonstration experiments”. One of main goals of both activities, which are held by the Department of Physics Education, Faculty of Mathematics and Physics, Charles University in Prague, is to increase students’ interest in physics.

Interactive Physics Laboratory

The main inspiration of our laboratory was similar project House of Science in Stockholm, Sweden. More information could be found in articles (Johannson & Nilsson, 1999 and Johansson, 2004). Before laboratory was established we made a small search among teacher’s opinions. The main goal of the laboratory was (and still is) to serve the needs of teachers and their students. Because of this reason we asked many question how the students’ visit should look like and what topics of experiments should be included. The results were presented at Girep 2009 in Leicester, UK. According to these results the scheme of students’ visit were planed and topics were chosen.

Students in the laboratory

The schedule of the visit is nearly always for each group of students individual. We try to adapt to schools in time. There is no fixed timetable saying “there is heat laboratory held on Monday”, or similar. The next phrase describes the most frequent scheme of students’ visit in the laboratory.

The group coming to the laboratory consists in most cases of 12 (max 16) students. The visit takes 120 minutes. Students are divided in groups. One group means no more than four students. Each group is working on different tasks and has its own instructor (future teacher studying at our department). There is always one common topic, but four different stands. We decided for this solution because of high price of some instruments. To provide all students at least some findings from all experiments there is a short “conference” held in the end of the students’ visit. Every group is in the beginning notified of their short
presentation. This action has a positive effect on their work. Knowing they have to present their findings they are pushed to formulate and summarize their results.

After first several visits we have changed the introduction. First we started with a short introduction: basic information about the laboratory and the topic, students’ tasks were introduced, risks in the laboratory mentioned, etc. According to students’ behaviour during the first part of the visit we realised that the break between their transportation from school and starting focusing on physics is too short. From this reason we extended the introduction part by adding a short demonstration concerning the common topic connecting following work of all groups (Figure 1). Students now use to have more time to start focusing on given tasks. There are also other benefits. Because we always try to choose fun demonstrations in which students can take a part, they very often lost the main of their fear and the chance that they won’t be ashamed to ask questions during their next work becomes higher.

When preparing experiments for students’ measurements (practical work) we always try to combine “professional” experiments done using special instruments and simple experiments with everyday life equipment. For example the Phywe apparatus (Coulomb potential and Coulomb field of metal spheres, 2012) is used for verifying Coulomb’s field around charged conductive spheres (Figure 2). On the other hand students do experiments with metalized ping-pong balls and use them in combination with an electronic scales for checking the Coulomb law (Figure 3). This experiment was inspired by the article (Cortel A., 1999).

**Students’ preparation**

Before coming to the laboratory students are given the task to go through the laboratory manual prepared by us. They also use the paper later in the laboratory during their measurements. There is always a big difference between honest diligent students and those who do not even open it at home. We observed that the group of students who went through the materials used to work much faster and ask more conversant questions.

**Feedback**

Students spend in the laboratory approximately two hours. The test searching knowledge benefits was not done yet. Writing a pre-test and a post-test would take too long time and reduce the visit. We decided to measure participants’ subjective experience related to the laboratory experiments. To reach this target we use The Intrinsic Motivation Inventory (IMI) (Intrinsic Motivation Inventory, 2012). The material was translated to Czech. Four scales suitable for the case of the IPL were chosen. The final version of our questionnaire (translated “back” in English) is presented in Appendix and contains following scales: Interest/Enjoyment (matching statements are 1, 5, 11, 15, 18, 21, 22), Effort/Importance (2, 6, 12, 19, 23), Pressure/Tension (3, 7, 9, 13, 16), and Value/Usefulness (4, 8, 10, 14, 17, 20, 24). Each statement was awarded by students on the scale from 1 to 7, where 1 means “not at all true”, 4 is “somewhat true”, and 7 “very true”. There are seven statements for both groups “Interest/enjoyment” and “Value/Usefulness” and there are five statements for the other two scales. Six statements are reverse. The score of each scale is calculated as the simple arithmetic mean of all relevant sentences’ scores. Results are presented in the figure 4. The questionnaire was filled by 53 students up to now. According to students’ answers they are interested in and enjoy activities done in the IPL (score 5.67). We can see that they also put a value and usefulness to these activities (5.46). On the other hand the result in “Effort / Importance” is not so high (4.89). Students’ feelings about tension and being under pressure are evaluated by the number 2.34.

**Collection of demonstration experiments**

The collection of demonstration experiments (http://kdf.mff.cuni.cz/pokusy) established in 2011 is a webpage containing detailed experimental manuals. The vision of such collection was first time presented at Girep 2011, Finland (Šabatka, 2011). Here we briefly describe the further development and a common situation of the collection.
The main idea of the collection is that it should help mainly starting physics teachers. Its structure and the content are prepared to reach this target. The website is based on Collection of physics tasks (Koupilová, 2008 & 2010), which helps us easily to structure the text. Each manual is divided in following parts: a motivation part / an assignment, a list of instruments, a description of the preparation and the demonstration (both supplemented by short video and figures), an analysis (a physical description / an explanation of presented phenomena), conclusion and comment. In comparison to last year the website is fully working. There are nearly 50 experiments (in Czech language) from the area of electricity and magnetism. Even the physics is multilingual and videos are non-commented (they could be used all over the world), to show how it works, we translated two experiments in English (http://kdf.mff.cuni.cz/pokusy/uloha.php?uloha=774, http://kdf.mff.cuni.cz/pokusy/uloha.php?uloha=768).

Summary

The interactive physics laboratory helps high school students and their teachers do experiments which cannot be done in their home classes from many reasons (mainly high price of required instruments). There is approximately one group of high school students per week attending the IPL. We hope the number will rise and we will have more classes in the future. In addition to that the laboratory is of course being used during seminars for our students (future physics teacher). According to the IMI based questionnaire and positive feedback from teachers we think that we are on the right way. We will continue in adding other experiments to the laboratory to cover the main topics. We will also collect more feedback from students. Our vision is to do a small research among the contribution to the students’ understanding of physics given by visiting and doing experiments in our laboratory.

The collection of demonstration experiments presents non-traditional manuals on physics experiments. We think the website is unique mainly thanks to its target audience: future and starting physics teachers. The internet is full of webpages describing experiments, but only few of them use instructional videos in combination with comments how to introduce and explain the physical phenomenon to students. The main current goal is to add next experiments in the field of electricity and magnetism. Then we will focus on the other topics.

We would appreciate if any teachers (or departments) from abroad would be interested in any of our activities. If you want to share experiences with an operation of a similar laboratory or if you want to share an interesting experiment, which could be added to the database, please contact us.

References


Šabatka Z.; Dvořák L.; Koudelková V. (2011). Demonstration Experiments in Electricity and Magne-

**Appendix**

**Figure 1.** Electrostatics course starts with demonstrations using Van der Graaf generator.

**Figure 2.** Experimental work using professional instruments: apparatus for measuring electric field around a charged sphere.
Figure 3. Experimental work using non-professional instruments: verifying Coulomb’s law.
Questionnaire – Interactive Physics Laboratory

Following statements are concerning you experiences with activities you have taken a part in during IPL visit. For each of the following statements, please indicate how true it is for you, using the following scale:

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<td>Not at all true</td>
<td>somewhat true</td>
<td>very true</td>
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**School:**
Secondary School (In Czech: Gymnázium.)
Vocational school

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<th>Statement</th>
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<td>1 I thought this activity was quite enjoyable.</td>
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<td>2 I put a lot of effort into this.</td>
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<td>3 I felt pressured while doing these.</td>
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<td>4 I think doing this activity could help me in understanding physics topics in school.</td>
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<td>5 I enjoyed doing this activity very much.</td>
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<td>6 I didn’t try very hard to do well at this activity.</td>
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<td>7 I did not feel nervous at all while doing this.</td>
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<td>8 I believe this activity could be of some value to me.</td>
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<td>9 I felt very tense while doing this activity.</td>
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<td>10 I think this is an important activity.</td>
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<td>11 This activity was fun to do.</td>
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<td>12 I tried very hard on this activity</td>
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<td>13 I was very relaxed in doing these.</td>
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<td>14 I think this is important to do because it can lead to better insight into appropriate physics topic.</td>
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<td>15 I thought this was a boring activity.</td>
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<td>16 I felt anxious while working on this task.</td>
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<td>17 I would be willing to do this again because it has some value to me.</td>
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<td>18 I would describe this activity as very interesting</td>
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<td>19 It was important to me to do well at this task.</td>
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<td>20 I think doing this activity could help me in next studies of physics.</td>
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<td>21 This activity did not hold my attention at all.</td>
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<td>22 While I was doing this activity, I was thinking about how much I enjoyed it.</td>
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<td>6</td>
<td>7</td>
</tr>
<tr>
<td>23 I didn’t put much energy into this.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>24 I believe doing this activity could be beneficial to me.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>
Here you can add your message to authors and courses leaders.

Figure 3. Summarization of students’ questionnaire answers.
Linking Different Domains of Physics through the Mathematical Tool of Integrals

Olga Gioka, Department of Physics, University of Ioannina, GR- 45-110 Greece

Abstract

This study is part of a larger, ongoing project on how best to prepare undergraduate physics students to become teachers in secondary schools. We report on our attempt to help pre-service students relate problems of different curriculum areas through the mathematical tool of integrals. The physics domains were those of kinematics, kinetic energy and work, dynamics, equilibrium and center of mass, thermodynamics and electromagnetic induction. We worked with sixty pre-service physics teachers during one academic year. The study investigated how the designed problems and our seminars facilitated physics understanding and problem solving skills. We conducted interviews with students based on their marked coursework and videotaped discussion between instructors and students. We also collected students' coursework and homework. Data analysis aimed at identifying their reasoning, difficulties and changes in problem-solving. Students improved their understanding of integrals and what the area under the graph represented. It is argued that students' difficulties with integration are due to lack of a deep conceptual understanding of physics and a sound understanding of the mathematical processes involved. We conclude with some recommendations for initial physics teacher education and physics education research.

Keywords: Initial physics teacher education, university physics, integrals, mathematics and physics

Introduction

The traditional teaching of physics in separate domains leads to rote learning and fragmented understanding that hinders deep understanding (Bagno et al., 2000). Students who complete introductory physics fail to see physics as a coherent knowledge structure (Redish et al., 1998). They see physics as a set of disconnected mathematical and physics equations that each applied to a small number of specific situations and that should be memorized.

In addition, mathematics, for many students, becomes a barrier to physics understanding and problem-solving. Students in calculus-based physics courses are often expected to have sufficient mathematical knowledge and skills to be applied to physics problems. Yet research on physics problem solving indicates that students’ application of mathematics knowledge in physics problem solving does not happen as often, easily and fast as we expect. As Tuminaro and Redish (2004) argued, this is not because students do not have the necessary mathematical background but because they cannot appropriately activate those resources in a physics context.

Integration is a powerful mathematical tool widely used in many areas of physics (i.e., mechanics, energy and work, electricity and magnetism). Many problems in physics involve setting up an integral to calculate physical quantities from other non constant quantities. Understanding of integration and integrals requires not only good mathematical knowledge but also a good understanding of the physical meaning of the variables and the quantity to be integrated. In typical problems in calculus mathematics courses, students are given integrals to compute. In contrast, problems in physics courses usually do not have predetermined integrals and they do not indicate that integrals are needed to solve the problems. Students should recognize the need for an integral, set up the expression for the infinitesimal quantity, accumulate the infinitesimal quantities and compute the integral. More importantly, they should be able to explain its physical meaning: what the infinitesimal quantity and the integral represent.

This research is part of a larger, ongoing project on how best to prepare pre-service physics teachers to teach in secondary schools (e.g., Gioka, 2012). The project is placed within the undergraduate program for physics students in our physics department. In the first three years of their undergraduate studies, our students take modules on mathematics, physics and participate in laboratory courses. In the fourth
year, those who want to become teachers, participate in a program mainly oriented to physics teacher preparation and their certification as qualified teachers. The design of our pre-service teacher program is based on the argument made by McDermott (1990) about the need to design ‘special’ courses for prospective physics teachers.

In this paper, we report on our study aiming to support pre-service physics teachers to relate physics problems of different domains through the mathematical tool of integrals. We want to take a close look at student understanding and reasoning when applying the integral concept in physics problem solving. The following two questions guided the study:

1) How do students understand what quantity has been represented by integrals in various physics problems?
2) How do their understanding of integrals and problem-solving skills change during one academic year?

**Literature Review**

Physics education research has demonstrated that students’ expectations can play a powerful role in how they use the knowledge they acquire in physics classes. Student expectations also play a powerful role in how they think they are supposed to use mathematics in their physics classes (Redish et al., 1998). Research on students’ application of calculus in physics suggested that students may not conceptually understand mathematical processes although they can easily carry out the calculations (McDermott, 2001).

To explore students’ understanding of integration and the relationship between the definite integral and the area under a curve, Orton (1983) and Artigue (1991) interviewed students on several tasks involving the concepts of limit and integration. Orton identified a range of difficulties they experienced: from conceptual errors to procedural related to integration. Artigue found that although most of the students could perform routine procedures for finding the area under a curve, rarely could they explain their procedure. Also, Yeatts and Hundhausen (1992) looked closely at students’ students’ difficulties when applying calculus in physics. They classified their difficulties in three categories:

(a) Difficulties with setting up an integral and understanding its physical meaning arose from students’ rote memory of, and hence, reliance on the symbols in each context.
(b) Difficulties occurred when the surface features of the problem hindered the underlying mathematical process.
(c) A third difficulty was due to the ‘compartmentalization of knowledge’, which occurs when students store knowledge of different disciplines in different ‘cabinets’ and activate knowledge in each ‘cabinet’ only in the corresponding discipline.

Another study investigated students’ use of mathematics when solving problems with integrals in electrostatics. Meredith and Marrongelle (2008) identified mainly two approaches by their participants. A part of students would recall a previously learned strategy when solving a problem. In other problems, students decided to integrate because there was a quantity that was non constant and it depended on another quantity. The recall and the dependence cues were the most common cues used by students to cue integration in electrostatics context problems. Wallace and Chasteen (2010) found that part of students’ difficulties with Ampere’s law was due to students not viewing the integral in Ampere’s law as representing a sum.

More recently, the study by Nguyen and Rebello (2011a) investigated how students understand and apply the area under the curve concept and the integral-area relation in solving introductory physics problems. They used a sequence of several problems involving the area under the curve concept and interviewed the participants. They found that only a few students could recognize that the concept of area under the curve was applicable in physics problems. Even when students could invoke the area under the curve concept, they did not necessarily understand the relationship between the process of accumulation and the area under a curve, so they failed to apply it to novel situations. They also found that when students...
were presented with several graphs, they had difficulty in selecting the graph such that the area under the graph corresponded to a given integral, although all of them could state that ‘the integral equals the area under the curve’.

Nguyen and Rebello (2011b) also investigated the common difficulties that students in introductory physics experienced when solving problems involving integration in the context of electricity. They conducted interviews with students in a calculus-based introductory physics course on several problems involving integration. They found that although most of the students could recognize the need for an integral in solving the problem, they failed to set up the desired integral. They argued and provided evidence that such a failure was due to students’ inability to understand the infinitesimal term in the integral and failure to understand the notion of accumulation of an infinitesimal quantity.

The pre-service teacher education program and the participants

In our undergraduate curriculum, physics education modules are taught in classes of 100-120 students and they are mainly lecture-based. During the last years (2007 onwards) we have run a larger project designed to prepare prospective teachers for particular aspects of secondary physics teaching (e.g., Gioka, 2012). In order to be able to work with smaller numbers of students and implement particular strategies, we organized two seminars with thirty students in each one. We worked with these sixty students during the first semester and the same students from the same cohort in the second semester. The sixty students who participated were at the final year of their undergraduate studies and volunteers for the research study. During the seminars, they worked in smaller groups of three. The participants had successfully completed all the mathematics and calculus-based physics modules in the undergraduate curriculum.

In the seminars, teaching was explicit. We wanted to support them by employing ‘scaffolding’ and questioning strategies to advance their thinking.

Instructors collected coursework and homework problems and they gave back them to students with written feedback. In many cases we asked students to re-work on them by taking into account the provided written feedback. We wanted them to respond to provided feedback in order to improve their solution and understanding.

The problems we used were either taken from the standard physics textbooks or designed by our team. All involved integration and calculation of integrals. They were problems on various topics and in various contexts of physics including kinematics, kinetic energy and work, dynamics, equilibrium and center of mass, thermodynamics and electromagnetic induction. The problems were used in the teaching and assessment process. The format of problems would vary during the period of one year. At the beginning of the academic year, we wanted to give more guidance on how to proceed (The details of one problem and its statement are provided in Figure 1). With time, we would give them freedom to choose the way they would work out the solution. Or, we would guide students through oral and written feedback to improve. All problems were clearly asking students to make their reasoning explicit. This was proved to be a valuable source of their difficulties and possible changes, improvement toward better understanding of integrals and integration.

Research Methodology

In order to document students’ understanding of integrals in physics problems, we are primarily interested in looking closely at students’ reasoning. Students were asked to ‘think aloud’ while working on problems and in groups of three during the seminars. Seminars were observed by two researchers and discussions during seminars were videotaped. Careful observations of students during the seminars can provide important insights that can help us interpret student responses. All interviews were transcribed verbatim.

Also, semi-structured interviews were conducted with students on the basis of their marked coursework and the problems used in instruction. This is what we call ‘problem-based’ interviews. The purpose of the interviews was to explore their way of thinking and reasoning in more depth and detail. Some questions asked in the interviews are shown in the Appendix.
We also collected students’ coursework and homework and looked through mistakes, difficulties and reasoning. Informal interviews provided additional information when required. This information together with the results obtained by the other methods of research can provide the kind of detailed knowledge necessary to answer the research questions.

Data analysis and limitations

In analyzing students’ answers and reasoning (quantitatively and qualitatively), we attempted to trace changes and possible improvement in students’ understanding of integrals. We looked for the most common errors and difficulties and the emergent themes. One goal of the study is to document changes and improvement in their understanding of integrals across the various curriculum areas of physics by collecting data through one academic year. Instead of employing pre- and post-tests, we wanted to collect rich data in order to explore the dynamism of student learning. There are obvious difficulties in monitoring the trajectories of students from initial performance on problem-solving to expert and improved. Therefore, Gupta, Redish and Hammer (2007) argued that the alternative is to study a cross-section of the population at various stages of development. In our case, we decided to look at students’ reasoning, difficulties and understandings related to integrals and integration during the one-year teacher education program.

We want to make full use of the advantages of the selected research methods to get into the detail of student difficulties and progress. On the other hand, the context of only one physics department and the certain number of the participants limit the generalizability of results.

Results and discussion

It took much time for students to explain their reasoning. As they justified in the interviews and in seminar discussions, they were not used to explaining their reasoning. In fact, in common physics modules and when solving problems they should reach the ‘right’ value without explaining how they worked out a solution. Also, at the beginning of the course they felt, to some extent, ‘threatened’ because ‘showing your reasoning to your instructors may be dangerous’ for the final grade one receives (their own expression in italics).

With time and instructors’ persistence they started making their reasoning explicit to co-learners and instructors in the seminars. They would also write down their reasoning, as required by the problems. The particular problem requirements encouraged students to express their reasoning in their own words and hence, enhance and develop deeper understanding. In our seminars, making explicit their reasoning facilitated the interaction with instructors (Gioka, 2006) and the provision of feedback (oral and written). Students reported that working on such problem format was a very meaningful process for them resulting to coherent understanding. Expression of their reasoning helped them improve their performance and understanding of particular steps of integration, as we will show in this section.

At the beginning of our program, we realized that students could develop strategies for solving problems and doing well in exams without understanding integrals and integration thoroughly. They learn by heart equations and formulae into which they plug numbers. For example, in a problem with an ideal gas and work done by the ideal gas, they applied a formula for the work without setting up the integral and explaining their reasoning. This step may be trivial for most students because they usually apply the formulae from the textbook without understanding what each term represents. This is because many have had high school or undergraduate physics classes in which plugging numbers into poorly understood equations sufficed to earn a good mark. It was also the case that many participants tended not to use calculus taught in mathematics courses (integrals and so on), while they would rely on physics formulae, secondary school mathematics and intuition. For example, we provided them with a problem in which the graph of net force F versus position x was given and asked to work out the work of the force over a displacement range. They worked it out by applying simple geometry to calculate the area under the curve which was a triangle. According to their explanations, this is because in secondary physics teaching they are not supposed to be using integration and integrals. Or, they said that they expected that physics education modules would not include complex mathematics and physics. This expectation is connected to the belief (also held by faculty members) that all physics and mathematics modules taught in the undergraduate program may be heavy, whilst physics education is much simpler and more straightforward. Students considered setting up and
computing integrals using the graph only when they were explicitly asked to proceed in that way. One can agree with Redish and colleagues that student expectations play a powerful role in how they think they are supposed to use mathematics in their physics classes (Redish et al., 1998).

We identified several conceptual, mathematical and reasoning difficulties related to what it means to understand and perform integration in a physics context. First of all, we found that students had difficulties in distinguishing variables and constants within an integral and in deciding on which variable to integrate. For example, in a thermodynamics problem, they should understand the concept of molar specific heat at constant volume \( C_v \) for an ideal gas, in order to decide on which variable to integrate. In other problems, they should make sure whether force \( F \) is \( F(x) \), a function of force with respect to position, or if \( F \) is \( F(t) \), a function of force with respect to time, or a function of force with respect to a different variable. Mathematics and physics may use the same notation or symbols to mean different things, thus causing difficulties to students. Here, difficulties may arise from students’ rote memory of the symbols in each context and reliance on them. With questioning and explicit teaching in the seminars, our participants became more careful on drawing their attention to the variable of integration and the constants. At the same time, attention to the variables is crucial towards better conceptual understanding and connection of mathematical and physics equations across different curriculum areas.

Most research studies investigated to what extent students are able to easily recognize the need for an integral in problems. Our study wanted to move further on to the next ‘steps’ in the integration progress. In physics problems asking for application of integration, students should work in four steps: they should recognize the need for an integral, set up the expression for the infinitesimal quantity, accumulate the infinitesimal quantities and compute the integral. That is, we wanted to look at, after them having seen the need for an integral, how they would proceed with:

1. setting up the expression for the infinitesimal quantity,
2. accumulating the infinitesimal quantities and finally,
3. computing the integral.

Most of our students did not have difficulty recognizing the need for integration in solving the problems. Setting up the expression for the infinitesimal quantity seemed to be the most difficult part of the integration process. We helped students with mathematical knowledge because our intention was not to test their mathematical skills.

However, students’ difficulties with setting up the expression for the infinitesimal quantity seemed to be related to conceptual understanding and understanding of mathematical processes. We found that students would set up an incorrect expression for the infinitesimal quantity because they could not understand its physical meaning. Most of our participants were not confident in describing and explaining its physical meaning. Many students would simply prefix “\( d\)” to whatever quantity was changing (i.e., force, velocity) without understanding the meaning of the infinitesimal quantity in the integral. This is consistent with the study by Nguyen and Rebello (2011a, b) in which lack of understanding of the physical meaning carried by the infinitesimal quantity caused students to ignore the infinitesimal term. Guiding the students to set up the expression for the infinitesimal quantity was the strategy employed by instructors to support students who could not easily set up the expression. For example, in the thermodynamics problem (Figure 1), we wanted students to understand what they are adding up and why, not only that they were adding something up. Attainment improved from 8% (at the beginning to 93% at the end).

After having set up the correct expression for the infinitesimal quantity, we found that most of our students had difficulties in accumulating the infinitesimal quantities. They would accumulate the infinitesimal quantities in the wrong way without attending to how the quantities should be added up. Thus, although in interviews and seminar discussions, most students indicated an understanding of integration as an accumulation process, they were not confident in carrying out the process. They had difficulties in understanding the accumulation process underlying the integral and needed detailed guidance. This is consistent with the study by Wallace and Chasteen (2010). They started with only 11% success to reach 96% near the end of the second semester.
We found that this difficulty may be attributed primarily to students’ inability to interpret the meaning of the infinitesimal term $dx$ in the integral, which is closely related to students’ lack of conceptual knowledge. We also found that in the last step of computing the integral students still had some difficulties. Although, we would expect the last step to be a straightforward task for students because they had practiced computing in their calculus courses (mathematics and physics), this was not the case. This is mostly because they were unable to interpret the physical meaning of the symbols and invoke basics mathematical equations. Students wanted to be given some help with formulae and asked for some assistance in computing integrals. At the beginning 16% students could correctly compute integrals, while near the end they reached to 98%.

Students had difficulties in explaining the physical meaning of the infinitesimal quantity $dx$, $dr$, $dt$ and what it represents in the integral. The infinitesimal quantity carries a physical meaning that must be understood when setting up the integral. For example, if $F(x)$ is a function of force with respect to position $x$, then $F(x)$ at position $x$ and the corresponding infinitesimal distance $dx$ in the direction to obtain the total work done over the whole distance. However, $\int dt$ means integrating the product of the force $F(t)$ at time $t$ and the corresponding time interval $dt$ to obtain the total impulse due to the force over the total time interval. In these examples, $dx$ and $dt$ not only indicate the variable of integration but also have their own physical meanings: infinitesimal distance and infinitesimal time interval, respectively. In common high school and undergraduate physics classes, the two cases are taught as totally different problems. Instead, we want to argue that when we teach these two cases we should try to connect and show what each infinitesimal quantity and each integral represents. Students’ sound understanding of what an integral represents, that is, a sum of infinitesimal quantities, may contribute to better conceptual understanding. In the seminars, we asked them to make connections between the above two curriculum areas by using the tool of integral. As the majority of them stated: “Now we can make connections between mathematical equations and conceptual ideas”. And not “see physics as a set of disconnected mathematical equations that each apply in a small number of specific situations and learnt by heart”.

Similarly, students needed help to understand and explain what each product $PdV$ represents. We encouraged them to continually make connections between concepts within different contexts. For example, both represent work.

Another issue is students’ understanding and interpretation of the meaning of the area under the curve. In our study, we found evidence of students’ failure in interpreting the meaning of the area under the curve. At the beginning of seminars, our students experienced difficulties to perceive the area under a curve as representing a quantity other than area (e.g., displacement, work done by a force, work done by an ideal gas and so on) because they did not consider the quantity being accumulated as a sum of infinitesimal bits that are formed multiplicatively. They had a rough idea of an integral as a sum of an infinite number of elements. Only a few students at the beginning could contribute a meaning to the area under the curve concept (what the area represented) in various physics problems. Although all of them could state that ‘the integral equals the area under the curve’ and they were able to calculate the area, they did not have a satisfactory conceptual understanding to be able to interpret its physical meaning or applying it to unfamiliar contexts. For example, in a problem in which a plot of acceleration against time was given, most of students could calculate the area under the curve but they could not explain their procedure and interpret what the area represented. Some students did not even realize why they were doing what they were doing. Or, we found that students could perform integration as a mathematical procedure with limited understanding that they were finding the area under the curve.

As students proceeded through our seminars and the academic year, they had become better at using the area under the curve in physics problems. We found that students needed help with understanding that the area under a curve may represent a quantity other than the area (not always the area, but also work done by a force, displacement, work done by an ideal gas and so on). Our instruction made this distinction and put emphasis on what each integral represents. The development of deep conceptual understanding and mathematical processes may account for better understanding of what the area under a curve represents.
Another aspect of students’ understanding of integrals, we attempted to look at, was their reasoning and way of working out problems involving negative areas in the graph. For example, in a problem we gave them a graph of a non constant force versus position in which a part of the curve was below the horizontal axis. We wanted them to calculate the work done by the force over a range of position for which the force would take negative values, too. In another problem, the force was given as a function of time on a graph, acting on an object along the x axis and the horizontal axis was below the time axis.

We wanted them to work out the speed and direction of travel at particular times. Initially, students had many difficulties since they stated that ‘the integral equals the area under the curve’ and wondering ‘but above what?’ In this case, the particular way of their reasoning proved hard to identify. It involved detailed probing of their understanding in a variety of physical situations and in a wide range of research methods (interviews, collected homework and above all, discussion in the seminars). Two of the main mistakes that students made were that they did not use the negative sign when they referred to the area under the horizontal axis and secondly, they resorted to formulae and equations by avoiding using integrals. Here, we wanted students to learn that the work done by a non constant force equals the area under the curve and the displacement axis, or the time axis, and a negative sign is needed.

Table 1 shows the most common errors and difficulties as coded and classified during data analysis. Table 2 shows how aspects of their reasoning and difficulties changed over the period of one year.

Students significantly improved their understanding of integrals and associated physics ideas with integration. Our participants’ proficiency with integrals and integration was better and substantial in the later lessons around the end of the second semester. Better performance on integrals means that the participants were more able to apply the already taught mathematical knowledge from calculus to the physics context. Also, students’ improved attainment in the later lessons provided evidence of improved conceptual physics understanding. As they noted in the seminars, instruction helped them better understand the mathematical processes and how mathematics expressions are related to the physics concepts. Also, the majority of them said that the seminars helped them to cross the gap between the mathematics, taught in a non-meaningful way, and physics which is often learnt by heart. ‘Now, mathematics makes more sense and makes teaching and learning of physics more meaningful’ (their own expression). Also, quite many of them said that they would wish that they had had such seminars in the first year of their physics classes and not in the final year and physics education classes because ‘that helps me a lot. I wish I had done it in my first year physics courses’.

Conclusions and Implications

Our findings align with and extend those from other research on students’ understanding and difficulties with integration. Most research studies investigated to what extent students are able to easily recognize the need for an integral in problems. Our study moved further on to the next ‘steps’ in the integration progress. We identified several conceptual, mathematical and reasoning difficulties. We found that the major difficulties students encountered when attempting to solve physics problems involving integrals were due to:

a) students’ inability to understand the infinitesimal term in the integral,

b) failure to understand the notion of accumulation of an infinitesimal quantity and, (c) difficulty in computing the integrals.

Their main difficulty was how to set up the integral and not the calculation itself. Other difficulties have to do with distinguishing variables and constants within an integral and making a decision on which variable to integrate.

Setting up the expression for the infinitesimal quantity seemed to be the most difficult part of the integration process. In addition, they made mistakes when they were asked to interpret the meaning of the area under the curve. Explicit teaching, instructors’ support and feedback, as well making explicit their reasoning were important for students’ improvement and better understanding of integrals.

We have argued that good performance on integrals requires related mathematical skills in integrating but also a deeper understanding of the underlying physics. Many difficulties are interrelated and interdependent with conceptual difficulties in mathematics and therefore, must be treated together. However, the difficulties...
are primarily conceptual, rather than mathematical. Consequently, if, as physics educators, we want to improve understanding of integrals, we should work on these aspects of teaching and learning integrals: setting up an infinitesimal quantity, accumulating infinitesimal quantities and computing integrals.

This study is not an evaluation of our instructional approach and seminars. Nor we want to make recommendations for the teaching of mathematics and physics modules at the undergraduate level. Our intention is solely to look at prospective physics teachers’ understanding of integrals and help them improve through our pre-service teacher education program. We believe that research should inform the development of programs for initial teacher education (McDermott, 1990). Further research is necessary to look at the same issues but by involving in-service physics teachers. ‘What do in-service physics teachers say about mathematics and physics separation?’ Also, we want to emphasize that physics staff should not rely on students’ mathematical understanding acquired from mathematic modules. Instead, they should teach mathematics in their physics classes.

Our study showed that the particular problem requirements encouraged students to express their reasoning in their own words and hence, enhance and develop deeper understanding. The participants improved, deepened their understanding and could better solve problems by using the same mathematical tool of integrals. Also, students reported that working on such format problems was a very meaningful process for them resulting to coherent understanding across various curriculum areas. They also appreciated the time and repeated practice in seminars. Development of and making explicit reasoning requires effort and it does take time. As Jon Ogborn (2012, in these proceedings) argued, serious thinking takes effort, attention and hence, it does require time and hard work.

Acknowledgements

I thank all the participants for providing access to their written work and instructors for making this study possible. I also thank Christakis Soutzios from the theoretical physics division in our department for his help with the development of problems.

References


**Appendix**

Questions used in the interviews: What does mean?

What is the physical meaning of dx? Why do you need to integrate?

What is the physical quantity related to the area under the curve?

Can you tell me the meaning of the whole integral that you have? I mean the process underlying integration.

What is the physical quantity that dx represents?

In your integral, what are the small pieces ρ(χ)dχ that you add? Can you explain the physical meaning of this term?

Could you please explain to me how you worked this out?
The figure below shows the graph of molar specific heat at constant volume for an object versus absolute temperature. Calculate the heat exchanged between the gas and its environment during a process at the same volume from 100 ºK to 500 ºK by:

a. estimating the area under the curve and,

b. integrating the function \( \frac{C_v}{R} \). Explain your reasoning.

![Figure 1. Problem on thermodynamics](image)

**Table 1. Common errors and difficulties with integrals and integration**

| Explain and make explicit their reasoning |
| Distinction between constants and variables |
| Make a decision on which variable(s) to integrate |
| Understanding the ‘integral equals the area under the curve’ |
| Understanding the physical meaning of the infinitesimal quantity |
| Understanding the negative curves |
| Understanding the physical meaning of the infinitesimal quantity |
| Reliance on secondary school mathematics, physics and intuition |
| Understanding the connections between different curriculum areas of physics |
Table 2. Summary of results from problems regarding the steps in the integration process. Percentages of students who worked out problems correctly (N=60 students).

<table>
<thead>
<tr>
<th>Steps in integration</th>
<th>1st month</th>
<th>3rd month</th>
<th>end of 1st semester</th>
<th>8th month</th>
<th>11th month</th>
<th>end of 2nd semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set up the expression for the infinitesimal quantity</td>
<td>8%</td>
<td>22%</td>
<td>46%</td>
<td>56%</td>
<td>74%</td>
<td>93%</td>
</tr>
<tr>
<td>Accumulate the infinitesimal quantities</td>
<td>11%</td>
<td>25%</td>
<td>44%</td>
<td>59%</td>
<td>78%</td>
<td>96%</td>
</tr>
<tr>
<td>Compute the integral</td>
<td>16%</td>
<td>58%</td>
<td>69%</td>
<td>81%</td>
<td>92%</td>
<td>98%</td>
</tr>
</tbody>
</table>
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Open Inquiry Investigations on Heat Transfer Performed by Undergraduate Engineering Students

Nicola Pizzolato, Claudio Fazio, Rosa Maria Sperandeo-Mineo and Dominique Persano Adorno, University of Palermo, Italy

Author Note
Nicola Pizzolato, Claudio Fazio, and Rosa Maria Sperandeo-Mineo, UOP_PERG (University of Palermo, Physics Education Research Group), Dipartimento di Fisica, Università di Palermo, Italia.
Dominique Persano Adorno, GIP (Group of Interdisciplinary Physics), Dipartimento di Fisica, Università di Palermo, Italia.
Correspondence concerning this article should be addressed to Nicola Pizzolato, Dipartimento di Fisica, Università di Palermo, Viale delle Scienze, Edificio 18, 90128 Palermo, Italia.
E-mail: nicola.pizzolato@unipa.it

Abstract
Many researches have shown the pedagogical effectiveness of structured inquiry as a high performance tool in science education of undergraduate engineering students. In this paper we report the preliminary results of an extended investigation on the efficacy of the application of an open inquiry approach to the consolidation of the physics concepts regarding the topic of thermal energy transfer. We selected a sample of undergraduate mechanical engineering students, who passed the examination of the basic physics courses with good marks. Firstly, we investigated about resistant misconceptions in thermal physics by administrating a pre-activity questionnaire. Even the best marked students showed several deficiencies for what concerns, in particular, the practical knowledge of the physics of energy exchange by thermal radiation. Our open inquiry activity involved the students in a highly challenging learning environment, starting from the problem of projecting a thermodynamically efficient space base on Mars. Students were asked to work in groups and to perform scientific investigations regarding the best materials to use in the construction and the best design strategies to practice in order to collect as much thermal energy as possible during the Martian day. Students were stimulated to design and carry out their own laboratory activity by collecting, processing and analysing data, in order to discover new concepts and obtain more meaningful conceptual understanding of the physics underlying the process of thermal energy exchange by conduction, convection and radiation. All groups of students were invited to share the results of their explorative works within each other during the final discussion. Lastly, a final post-activity evaluation test was administered. Our open inquiry learning path has proved to be a great opportunity of enhancing the practical and reasoning skills of our engineering students. Here we discuss in detail the advantages and limits of the open inquiry-based teaching approach.

Keywords: engineering education, open inquiry learning, nature of science

Introduction
The emergence of an international network of social and economic systems and technology-related processes is rapidly changing the requests of the professional qualities of engineers, who are often asked to practice within interdisciplinary contexts and demonstrate flexibility, creativity, particularly in the design process, dynamism and innovation (National Academy of Engineering, 2012). Graduate engineers should be able to demonstrate both specialist-discipline knowledge, ability to solve practical engineering problems, and design skills based on innovative thinking (Nguyen, 1998; National Academy of Engineering, 2004, 2010). An effective and efficient engineering instruction, should be able to train students towards a deeper understanding of fundamental concepts and, at the same time, develop and strengthen their reasoning skills and transversal abilities, enabling graduates to immediately engage in engineering practice (see Borrego & Bernhard (2011) and references therein).
In the context of K-12 science education, many reports propose a new vision of scientific instruction, suggesting to switch from a passive lecture-style teaching to a more active and student-centred teaching strategy (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2000; Rocard et al., 2007). Very recent updates of the American standards of scientific education strongly encourage the engagement in the practices of engineering design, which is considered equally important in the process of learning science as the engagement in the practice of science (National Academy of Engineering and National Research Council, 2009; National Research Council, 2012).

In this context, Inquiry Based (IB) science education represents the natural framework to develop opportunities of learning science concepts in terms of an active construction of meaningful knowledge and stimulate high levels of critical thinking skills (Llewellyn, 2002). In inquiry based learning, students are engaged in identifying relevant questions, searching information, collecting data and evidences, both in laboratory and real life environments, building descriptions and explanation models, communicating and sharing their findings. Depending on the amount of the information and support provided by the teachers, students may be involved in four levels of inquiry: Confirmation, Structured, Guided, and Open Inquiry (Schwab, 1964; Herron, 1971; Banchi & Bell 2008). In Confirmation Inquiry students are introduced to basic laboratory activities, such as collecting data, with the teacher providing both the question and procedure, and being the results known in advance. In Structured Inquiry the question and procedure are still provided by the teacher, but students generate their own explanations on the basis of their investigation results. In guided inquiry the teacher provides students only with the research question, and students design the procedure to test their working hypothesis. In Open Inquiry (OI) the teacher creates a context by presenting a multidisciplinary view of a theoretical or real-life phenomenon, after which the students start defining relevant questions, design and carry out their own investigations, communicate and share their results. In OI based instruction students have the purest opportunities to act like real scientists, reinforcing their reasoning skills and becoming aware of the process of scientific inquiry and of the nature of science (Schwartz, Lederman, Crawford, 2004; Flick & Lederman, 2006; Lindsey, Hsu, Sadaghiani, Taylor, and Cummings, 2012; Capps & Crawford, 2012).

While IB teaching strategies of science in K-12 grades of instruction are increasingly developing (e.g., Mooney & Laubach, 2002; Crawford, 2007; Minner, Levy & Century, 2010; Pyatt & Sims, 2012), at university level physics education is still mostly based on courses which are aimed firstly at introducing theoretical concepts and, only as a second, at developing practical skills through laboratory activities, which have often a pure demonstrative purpose and do not train the students to effectively inquiry the observed phenomenon. This approach is hardly successful, because, as it is well known, any mental construction, i.e. any mental model (Greca & Moreira, 2000), is deeply rooted on experience and students rarely fully understand a theory, even if currently accepted, if it is left far from a direct experimentation.

In this paper we address the problem of providing advanced engineering undergraduate students with a learning environment able to stimulate an effective understanding of the physics concepts underlying the complex world of thermal phenomena. Thermal science has always been considered a particularly tough discipline, because of the difficulties faced by the students at any level of education to overcome persistent misconceptions due to the common-sense experience of events governed by the intrinsic properties of matter (Streveler, Olds, Miller, & Nelson, 2003). Very recently, two studies confirmed the presence of robust misconceptions in undergraduate engineering students, even after having attended a semester or more of traditional instruction on thermal science (Streveler et al. 2011; Prince et al. 2012). Moreover, a recent study has shown the pedagogical effectiveness of guided inquiry-based activities, concerning the topic of thermal energy transfer, in courses for chemical engineering undergraduates, who achieved higher overall scores on the post-activity assessment of understanding critical concepts (Nottis, Prince, & Vigeant, 2010). While teaching strategies based on structured inquiry have shown their efficacy mostly when the target of instruction is the students’ mastering of contents, guided inquiry appears to be the most appropriate approach for developing an effective understanding of critical concepts and a deeper awareness of the nature of science (e.g., Tabak et al., 1995). Concerning the OI approach, it has been shown that it can sometimes produce negative motivational effects, such as the frustration due to achieving undesirable results, that could affect the successful completion of the learning process (Trautmann, MaKinster, & Avery, 2004; Quintana, Zhang, & Krajcik, 2005). Other studies, on the contrary, assert that only the adoption of an OI approach makes possible the achievement of higher levels of critical
thinking skills and a deeper understanding of the nature of science (Yen & Huang, 2001; Krystyniak & Heikkinen, 2007). Open inquiry is considered a dynamic learning process in which a continuous and renewed thinking involves flexibility, judgment, and contemplation, as part of the changes that occur in the course of inquiry (Zion et al. 2004). Moreover, the dynamic characteristics of an open inquiry process emphasize the perspectives of thinking about the process and affective aspects, such as curiosity, which are expressed in situations involving changes and uncertainty.

In this paper we present some preliminary results of an extended investigation regarding the study of the efficacy of an OI based learning method for a group of advanced engineering undergraduates, who persist to show conceptual problems and experience difficulties on applying the studied theories to solve practical everyday problems. To the best of our knowledge, an OI approach has never been adopted in advanced engineering education of undergraduates in the study of thermal phenomena. At the Mechanical Engineering Faculty of the University of Palermo (Italy) we have activated a pilot project, in which undergraduate students are involved in a high challenging research-like work on the topic of thermal energy transfer, oriented towards the practical application of the physics concepts which students should have learned in their previous traditional courses. The general objective of the project is to investigate the efficacy of an OI based learning environment for a sample of students, having college-level physics knowledge background, but still showing conceptual difficulties, in order to (a) correct resistant misconceptions, and (b) help them to overcome the difficulties that they experience in applying their theoretical background of knowledge to face practical everyday problems in thermal science. Finally, we also investigate on the opportunity for an OI based instruction to strengthen the reasoning skills of undergraduate engineering students and their abilities to carry out a scientific experiment.

Method

This study was carried out by selecting and motivating a sample of students to carry out independent OI-based research-like activities, within a framework provided by expert educators in the context of an effective learning of thermal science in engineering advanced students. In this paper, pre-instruction data, recorded by means of a questionnaire dedicated to investigate students’ conceptual difficulties, are compared with post-instruction outcomes. Moreover, results are also drawn from the analysis of the students’ logbooks of experiments, final scientific reports and oral presentations. The lab sections were also entirely video-recorded, but the results obtained from the video analysis will be presented and discussed in a subsequent paper.

Sample Selection

Our sample includes thirty undergraduate mechanical engineering students, being at the second or third year of their curriculum program. They have attended the first-year introductory physics courses and already passed the related examinations with marks greater or equal than 24/30. In particular, a first-year university background of knowledge includes a specific theoretical introduction to the concepts of thermal science and a more technical instruction on applied thermodynamics. All students were invited to join the project on a voluntary base after a brief presentation made by the authors at the Faculty Council for Engineering, where the general objective of the project was illustrated. Students involved in this study have never had specific instruction about the process of scientific inquiry and never participated to other OI-based learning programs.

During all the stages of the project, the students’ learning activities were supported by two educators (N. P. and D. P. A.) having more than ten years of expertise in the field of scientific research and on teaching physics at both high-school and university level courses.

Activity Description: Mission to Mars!

Our OI activity involved the students in a highly challenging learning environment, starting from the problem of designing a thermodynamically efficient space base on Mars. The project was developed across four main phases described in the following.

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Phase 1: Presentation (description and motivation) of the project. The students were invited to take part to an experimental project aimed at searching for design schemes and best materials to use for the construction of such a Martian base; more specifically, they were requested to point out the best design strategies to put in practice for collecting as much thermal energy as possible during the Martian day, and avoiding heat dispersions during the cold night. Students were supposed to work in groups and to perform scientific investigations devoted to the design, realization and testing of smart devices, having physical characteristics able to maximize the capture and storage of thermal energy from the Sun and high insulating efficiency. All groups of students were invited to carry out their own experimental work, by taking into account the physics underlying the process of thermal energy exchange by conduction, convection and radiation. Educators provided a brief description of the context in which students’ work would have been developed and the motivation for an active participation.

At this stage, all students participating the project answered to a pre-instruction questionnaire containing fifteen open-answer questions, concerning everyday experiences on thermal energy exchange. The questionnaire was developed and content-validated (Jensen, 2003) by the authors in collaboration with twelve faculty professors having long experience on teaching physics at engineering, by following the standards for education and psychological testing (American Educational Research Association, American Psychological Association, & National Council on Measurements in Education, 1999). Moreover, the questionnaire was developed through a six-month long activity of interviews to first-year university students involving their common difficulties experienced in learning thermal science concepts. The main topics covered by the questionnaire concern the following physics concepts: absorption of visible radiation, emission of thermal radiation, heat, specific heat and heat capacity, transfer of energy by thermal conduction and convection. The questions report practical experiments or real-life problematic situations in which a thermal phenomenon is described and the students are asked to give their personal explanation, providing a convincing motivation grounded on the studied physics theories. As an example, we report here two selected questions:

#4. Two equal plastic bottles, the first one filled with water the second with sand, having almost the same weight, are exposed to the sunlight in the same way and for the same time interval (15 minutes); which of the two bottles reaches the higher temperature? Explain your answer.

#6. Two ice cubes are extracted from the freezer and placed on top of two plates, both left at room temperature and made of the same material (aluminum). The plates have the same surface area but one has double thickness with respect to the other. In which plate the ice melt faster? Explain your answer.

Phase 2: The planning. All student groups were asked to plan in advance a set of experiments to be carried out during four lab sections. They were preliminarily invited to explore the laboratory in order to verify the available materials and measurement facilities and, successively, to begin the design of their own experiences. The educators asked the students to plan in detail their experiments and to write the planning of all their experimental activities into a document, for subsequent analysis. At this stage, students were strongly encouraged to feel themselves free to explore, even leaving the laboratory to move outside, if needed, or to bring inside home-made resources.

Students were informed about the opportunity to use all campus libraries and internet resources to gather literature. The educators suggested a preliminary search for information, but always left the students free to plan the experiments by following their own procedure.

Phase 3: Execution of experiments. Students were stimulated to carry out their own experimental work in the most independent way they were feeling confident to do. On average, students spent about thirty hours to complete four cycles of laboratory activity, by collecting, processing and analyzing data. Students used logbooks to note the followed procedure, the difficulties encountered throughout the activity and the changes they made during the inquiry process. They acquired the data by means of a system of sensors connected to computer interfaces. In Figure 1 we show a collage of photos taken during the development of this phase of the project.
Phase 4: Outcomes and conclusive reports. Each group of students shared the results of their scientific investigations with all the other participants during the development of the project activities. A final report and an oral communication describing their most significant experimental results were presented by each group. At the end of all activities, the same pre-instruction questionnaire was re-administered.

Results

The analysis of student learning involved two main aspects: the first one related to their understanding of physical concepts, the second one related to their awareness of the scientific procedure concerning the different steps of their inquiry approach to the posed problem. The results reported in this paper are mainly based on the analysis of the students’ answers to the questionnaire.

Before the beginning of the project, students were not informed about the duty to answer to the same questionnaire prior to and after instruction, so they answered to the test, during the first introductory meeting, by considering the questionnaire only an instrument for educators to assess their initial competences. After that, they planned the experiments they believed more significant by following only the aim of the research project and executed their activities not considering the opportunity to test in laboratory some problematic situations presented in the questionnaire. At the conclusion of all activities, they were invited to review their pre-instruction questionnaire with the chance to change the answers given at the beginning. The OI learning activities carried out by our students were not directly related to the experimental contexts proposed in the questionnaire. As a consequence, the questionnaire has been used to evaluate the effectiveness of an OI based learning method to help the students to overcome conceptual difficulties and improve their critical reasoning skills. In the following, two research questions are addressed with both quantitative and qualitative research methods.

Research Question 1:

Which cognitive constrains and conceptual difficulties affect the understanding of thermal phenomena in undergraduate engineering students facing practical problematic situations which require an effective application of their background of theoretical knowledge on thermal science?

Students’ answers to the pre-instruction questionnaire were independently analyzed by the researchers, authors of this paper. A common finding was the evidence that, even after a semester of university level physics instruction, a significant fraction of students still show several problems in the understanding of basic concepts of thermal science, such as temperature, heat, thermal energy, thermal conduction, convection and radiation heat transfer. A comparative study has been performed by the researchers in order to achieve a global consensus on the classification of students’ answers with respect to the conceptual problems detected. The inter-rater reliability was very high, reaching a value of about 96%, since only in few cases different interpretations to a student response were proposed, while many other students’ answers were similarly interpreted and classified. As a result, all students’ problematic answers were accurately studied and grouped within eight clusters of main learning problems, which are listed in Table 1. Some of these problems are related to well known misconceptions, such as confusing heat with temperature or consider heat as an intrinsic storable quantity, while some others appear to be a sort of forgetfulness on taking into account important mechanisms of energy transport, such as convection or thermal radiation.

The percentage of students who completed the questionnaire by giving at least one of the problematic answers included in the clusters of Table 1, during the pre and post-activity administration, are compared in Figure 2. Engineering undergraduates, having received a traditional, transmissive and mostly theoretical instruction, continue to experience severe difficulties to manage everyday phenomena concerning the topic of thermal energy exchange. When facing the pre-instruction questionnaire, some students started by opening the handbook of engineer, trying to catch the right formula to be used in answering the questions. However, differently from usual engineering examinations, the questionnaire was developed with the specific aim to investigate the students’ abilities to face and solve practical problems that could be encountered

A paper reporting the complete analysis (qualitative and quantitative) of all collected data is in preparation.

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in real world contexts and students showed significant difficulties both to identify the dominant transport mechanism of thermal energy and/or the relevant physical quantity involved in the process.

The analysis of pre-instruction questionnaire answers shows four clusters with a percentage of students greater than 50 %, namely C1, C2, C3 and C8, with cluster C1 even reaching 72 % and cluster C3 83 %. While the problem associated to cluster C1 is a typical residual misconception of younger learners at lower grades of instruction, the problems of clusters C2 and C3 are symptomatic of students' difficulties to identify the dominant mechanism of energy transport (C2) or key physical quantity involved in the process (C3). Even cluster C7, with a percentage of 60 % of students, represents a problem of considering all the relevant heat transfer mechanisms. The problem of “forgetting” to mention convection or thermal radiation does not occur for thermal conduction, probably because this latter transport mechanism is better “known” by the students, though the other two are equally experienced by the students in their everyday lives, but without a real awareness. Thermal conduction needs a medium to transport the energy and students seeing the medium can easily imagine something (heat) that is traveling across it. Convection needs a medium too, but students have more difficulties to figure out the motion of the particles when the fluid is invisible, such as air. In this view, thermal radiation, being able to travel in the vacuum, is the transport mechanism most easily forgotten, even if students are, of course, aware of the heating by solar radiation. Our pre-instruction results confirm the inefficacy of a traditional lecture based courses of physics instruction even in advanced engineering education.

**Research Question 2:**

*Is the open inquiry approach, adopted in a learning environment dedicated to the carrying out of scientific research-like activities, useful to help engineering students to overcome the difficulties that they experience in applying their theoretical background of knowledge to solve practical everyday problems in thermal science?*

Questionnaire results collected at the end of the open inquiry project activities show a clear reduction in the percentage of students giving problematic answers (see Figure 2). In particular, the number of students answering within clusters C1, C2, C3 and C5 has decreased up to almost half the corresponding percentage. The most significant improvement is observed in cluster C4, while the most resistant problem regards the underestimation of the effects due to the radiation heat transfer (cluster C7). By averaging over the all cluster data we find a global reduction of problematic answers of about 55 %, which corresponds to a significant improvement of students’ effective understanding of the basic concepts of thermal physics.

Before this project, the majority of our students ignored the significance of carrying out activities in the context of a scientific research. Many of them experienced the science laboratory at the high school through some demonstrative activities performed by their teachers, but they have never been actively involved in a physics laboratory at university before. For more than a semester, these students have been instructed by following a traditional teaching approach and trained to solve specific problems on thermal physics, even more complicated than those proposed in our questionnaire. However, this teaching strategy has proved to be ineffective to prepare future engineers to face unexpected problematic situations, because students were trained only to mechanically apply some mathematical formula within a standard procedure to the problem resolution, without any reasoning effort in searching for the procedure itself.

Within this pilot project, students, for the first time in their academic studies, were left free to explore the world and find a solution by themselves to the proposed research problems.

Preliminary results, obtained by the qualitative analysis of the documents developed by the students during the OI project and partly by the detailed study of the videos, allow us to make some inferences about students’ understanding of the procedures involved in the scientific inquiry. They learned how to conduct a scientific investigation, starting from an initial collection of information (literature) on the topic, and moving across a planning phase of activities, the design and realization of measurements, the gathering and analyzing of the data, the formulation of hypothesis and modeling, drawing conclusions. The choice made by the educators to drive the students’ OI of thermal phenomena within the context of a space science challenge (Mission to Mars!) strongly motivated the students. They participated to the
activities with excitement, being convinced of the importance of actively participate to a real research experience. This strong motivation avoided any negative psychological effect that could be observed in low-motivated open inquiry environments, such as frustration caused by mistakes or unexpected results, lack of curiosity or distractions.

The analysis of students' logbooks makes evident that students gained awareness of the importance of (a) the documentation, not only at the beginning but extended throughout the entire process, (b) the need of maintaining constant conditions during an experiment, (c) of observation reliability, (d) repetitions of measurements, using statistics, (e) taking the boundary conditions under control, and (f) interacting and sharing the results of their work with the other people involved in the same research.

Summary and Conclusions

An OI learning environment has been activated at the Faculty of Engineering of University of Palermo, Italy. Selected students, having attended college-level physics courses with traditional teaching approaches and being assessed with high grades in related examinations, participated to a pilot project on the application of an OI-based strategy to strengthen their practical and reasoning abilities and allow a more effective learning of the thermal physics concepts. Students spent a total amount of sixty hours to plan and realize a complete scientific research, concerning the experimentation of ideas, the design and practical realizations of smart devices, aimed at being useful in a hypothetical project about the construction of a thermodynamically efficient space base on Mars. Undergraduate mechanical engineering students were stimulated to design and carry out their own laboratory activity, with the aim of obtaining a more meaningful conceptual understanding of the physics underlying the process of thermal energy exchange by conduction, convection and radiation.

Even if already instructed by traditional courses on thermal science, the presence of residual misconceptions on basic concepts and several difficulties to face practical everyday problematic situation, in which a dynamic thinking is necessary to find a solution, were observed on a significant fraction of the students answering to a pre-instruction questionnaire. During the project activities, students faced some unexpected results from their experiments, but, being strongly motivated by the importance of conducting an experiment by themselves and within the attractive context of space science, they never experienced negative psychological feelings. They learned that unexpected results or failures are also results, because they help to rule out incorrect hypotheses and stimulate to think how to take into account real-world effects in the theory. At the end of all activities, the students answered to the questionnaire in a different way, by firstly inquiring on the described phenomenon and reasoning about the dominant transport mechanism and the most relevant physical quantity involved in the process. They achieved a global improvement of their conceptual knowledge and practical and reasoning skills, in terms of a 55% reduction of problematic answers to the post-instruction questionnaire. We believe that teaching and learning strategies, within an open inquiry based learning environment, developed across experiences more extended in time, should bring about to even better results. An important component in implementing open inquiry is the teachers' ability to motivate their students to ask those questions that will guide them through their inquiry (Chin, & Chia, 2004). In this respect, a critical point is represented by the need of a good teacher training path.

Traditional methods of teaching science, mainly based on transmission of information and laws, bring about a not lasting and effective learning. Theoretical descriptions of the scientific method procedures oversimplified scientific activity and fails to engage learners in a deep understanding of contents. Research like activities, within an OI-based learning environment, should be included in standard curricula of engineering education for undergraduates, as a valid integration to traditional teaching. In this way, it could be possible to achieve a more useful and effective meaningful knowledge on difficult physics concepts, promoting the strengthening of the reasoning skills of future engineers and their vision of the nature of science.
Acknowledgments

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References


**Table 1.** List of main problems within which students’ problematic answers were clustered.

<table>
<thead>
<tr>
<th>Label</th>
<th>Detected problem on physics concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Heat considered as a storable quantity</td>
</tr>
<tr>
<td>C2</td>
<td>Thermal conduction instead of thermal radiation</td>
</tr>
<tr>
<td>C3</td>
<td>Thermal conduction and insulation instead of specific heat or heat capacity</td>
</tr>
<tr>
<td>C4</td>
<td>Thermal radiation instead of specific heat</td>
</tr>
<tr>
<td>C5</td>
<td>Bigger object means greater heat capacity or resistance to change in temperature</td>
</tr>
<tr>
<td>C6</td>
<td>Temperature instead of heat</td>
</tr>
<tr>
<td>C7</td>
<td>“Forgetting” to mention thermal radiation</td>
</tr>
<tr>
<td>C8</td>
<td>“Forgetting” to mention convection</td>
</tr>
</tbody>
</table>
Figure 1. Collage of pictures taken during the work of the students involved in the OI-based learning environment dedicated to the pilot project “Mission to Mars”.

Figure 2. Percentage of students who answered the questionnaire by providing at least one of the problematic answers defining the clusters of problems listed in Table 1. Black and grey columns indicate pre-instruction and post-instruction data, respectively.
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Reconsidering Some Aspects of Inquiry Based Science Education: A Case Study on Model Based Inquiry

Claudio Fazio, Onofrio R. Battaglia & Rosa Maria Sperandeo-Mineo, UOP_PERG (University of Palermo, Physics Education Research Group), Dipartimento di Fisica, Università di Palermo, Italia.

Correspondence concerning this article should be addressed to Claudio Fazio, Dipartimento di Fisica, Università di Palermo, Viale delle Scienze, Edificio 18, 90128 Palermo, Italia. E-mail: claudio.fazio@unipa.it

Abstract

In this paper we report about a research focused on the development of explicative competences in engineering freshmen at University of Palermo, Italy, through a 20 hour course focused on Model Based Inquiry (MBI) in physics. The results of a pre-test and of a post-test are studied by means of quantitative analysis methods. The students are first classified into three ‘profiles’ related to the mental models they deploy when asked to explain situations coming from their past experience as students, or from real life experience. The possible effects of the MBI approach on the students’ use of models are, then, discussed.

Introduction

In the last few years, researchers in science education have been increasingly interested in the role of models in science teaching, and a wide range of research publications on this matter, from various viewpoints (Clement, 2000; Gilbert, 2000; Greca & Moreira, 2000 & 2002; Coll et al., 2005), can be found. In particular, it has been shown (Niss, 2001) that models can be used in science and mathematics education to help students to analyze and assess a given situation, consolidate the analytical skills acquired during learning and improve learning due to specific, scientific contexts in which models are constructed and discussed.

Two pioneering researchers (Johnson-Laird, 1983; Norman, 1983) introduced the term ‘mental model’ and defined its main characteristics as an internal representation that people form and use while interacting with the environment (problem, system, etc…). To a greater or lesser extent, this representation contains structural information about the properties of the system and functional knowledge about its behavior. Greca and Moreira (2000) defined a mental model as a personal representation which acts out as a structural analogue of situations or processes. The individual’s reasoning when he or she tries to understand, predict, or explain the physical world is based on mental models.

This paper describes some results of a research study concerning the design and implementation of a learning environment for undergraduate science and technology students, focused on modeling procedures. Given the complex nature of the content (learning about modeling procedures) and our interest in refining a generative and predictive framework for learning in a complex system (Reeves, 2006), our research has been based on some aspects of the ‘Modeling Theory’ (Hestenes, 1987), of the ‘Design Experiment’ (Kelly, 2004) and Model Based Inquiry (Windschitl et al., 2008) methodologies. All involve i) the analysis of resources/mental models and prior knowledge the students bring to the task; ii) a subsequent detailed engineering and testing of specific form of learning environments for students aimed at developing “defensible explanations of the way the natural world works” (Windschitl et al., 2008).

The results we discuss here regard the analysis of some conceptions and mental models undergraduate students deploy when they are asked to create explanations for situations coming from common life or related to already constructed, and studied, models. A specially designed questionnaire is administered to a student sample before and after instruction in a 20 hour course, and the answers are analyzed by studying the similarity trees (Gras et al., 2008) that can be built on the basis of a phenomenographic (Marton & Booth, 1997) categorization of the answers. Our research sample consists of 34 freshmen, enrolled in the 3-year bachelor degree program for Chemical Engineering at UniPa, during the Academic Year 2010/2011. During the 1st semester the students attended general mathematics, physics and inorganic chemistry courses, and already sustained the related examinations.
By following the general theoretical framework discussed above, we formulated the following research questions for this study:

- How can we classify the mental models that a sample of university freshmen deploy when asked to create explanations for proposed situations?
- Can a learning environment, based on collaborative inquiry and involving the presentation of problematic situations and their analysis through lab work and microscopic modelling, help students to focus on the construction of explicative models of phenomena, modifying the mental models evidenced before instruction?

**Methodology**

The study is based on quantitative research methods. It involves the analysis of data obtained by the administration of an open-answer questionnaire to our student sample before (pre-test) and after (post-test) instruction. During the 1st semester inorganic chemistry course chemical kinetics was one of the main subjects, although it was presented by the teacher mainly from a theoretically point of view. For this reason in the questionnaire students were requested to first discuss a real life situation (the evaporation of a water puddle at different environmental temperatures) dealing with a typical chemical kinetics subject, the Arrhenius law (Pauling, 1988). Then, they were asked to try and explain the law, and discuss other phenomena that can be modelled by it. The questionnaire items can be found in the Appendix.

The questionnaire analysis was conducted in three separate stages. In the first one, an ‘a-priori’ analysis of the possible answers to the questionnaire items was performed. According to Brousseau (1997), this analysis allows the answering strategies expected from students facing a problematic situation, and the potential alternative responses that may appear, to be highlighted. This can be very useful for the researchers, who can content-validate the questionnaire (Foxcroft et al., 2004), also highlighting weak points in the questions while searching for possible student answering strategies, and modify them before administering the questionnaire. The analysis is conducted independently of the observation (hence the term ‘a-priori’), in order to provide a reference point for the subsequent study of the ‘post-observations’, i.e. the actual student answers to the questionnaire items.

In order to make this questionnaire validation stronger, the a-priori analysis was independently performed by the three researchers and then a consensus was negotiated to obtain a shared version that has been optimized to the research aims.

In the second stage, actual students’ answers to the pre-test were independently analyzed by the researchers, by comparing them with the strategies hypothesized during the a-priori analysis. From the comparison it emerged that some of the hypothesized answering strategies were not used by the students and, by contrast, that some unforeseen strategies were put into action. In line with previous research (Gras et al., 2008; Fazio et al., 2012) these strategies were ‘a-posteriori’ added to the a-priori answering strategies, in order to obtain a global list of 61 strategies that can be used to better classify student behavior. This list is reported in the Appendix. Each question is followed by the set of possible strategies we hypothesized the students would put into action when answering the question, and the unforeseen strategies, in italics.

During the pre-test analysis each researcher used the list to draw up a table summarizing the strategies actually used by each student to answer the questions. The inter-rater reliability of the analysis was very high. Discordances between researcher tables were found in some cases when a student answer was classified considering not just one of the a-priori/a-posteriori strategies, but two or more of them. In a few cases discordances were due to different researcher interpretations of students’ statements. This happened 19 times when comparing tables of researchers 1 and 2, 17 times for researchers 1 and 3 and 16 times for researchers 2 and 3. Hence we obtained percentages of accordance of about 99% between the analysis tables of each researcher couple. The differences between the three tables were compared and discussed by the researchers to reach a consensus on a common table to use for the study.
The careful reading of the students’ answers within a framework provided by domain-specific expertise and previous research in the field of the description of student modeling competencies (Sperandeo-Mineo et al., 2006) allowed us to classify the student responses in three phenomenographic categories: Everyday/Practical, Descriptive and Explicative answers, as described in Table 1.

**TABLE 1**

In the last stage of the questionnaire analysis, we built a table that identifies three ‘profiles’ containing the answering strategies that can be considered typical of each answer category reported in Table 1 (see the Appendix for more detail). Each profile defines the ‘ideal model’ of a student answering all the questionnaire items by always demonstrating a given answering category. These profiles, reported in Table 2, have been used for a quantitative analysis of the research data, which is further explained in the next section.

**TABLE 2**

After the pre-test analysis, whose results are reported in the next section, students have been administered with a 20 hour course based on a Bounded/Open-Inquiry approach (Wenning, 2005) and focused on model construction, use and development (Windschitl et al., 2008). This setting sees a more prominent role for the student in the inquiry activities than for the teacher, with the general aim of developing defensible explanations of the way the natural world works, and generalizing them to a wide range of similar situations/phomena (Olson & Loucks-Horsley, 2000, p. 29; Windschitl et al., 2008). After the key subjects/phomena have been chosen, the first requirement is to connect them to student experience or interest in order to stimulate the students to search for an apprehensible underlying explanation. Then students:

1. find resources to develop tentative representations of the phenomena and develop questions aimed at analyzing structures that may explain the target phenomena;
2. generate hypotheses about functioning mechanisms of the phenomena;
3. determine what constitutes evidence with respect to the aims and give priority to it in responding to questions;
4. argue about evidence and formulate explanations after summarizing it;
5. examine various resources and connect explanations to them and to scientific knowledge;
6. form reasonable and logical arguments to communicate and justify explanations, in order to build a shared understanding of the subjects dealt with.
7. More details about the course development are discussed in a paper to be published in 2013.

Immediately after the class activities a final questionnaire, identical to the initial one, was administered and analyzed by using the same methods adopted for the pre-test analysis. The results are discussed in the next section.

**Data and findings**

In this study we use a Statistical Implicative Analysis (SIA) (Kuntz & Gras, 2008) function, the similarity index. It is mainly used here to reveal if there is a grouping of student behaviors and if it is possible to identify clusters of behavior with respect to the similarity to the ideal profiles we discussed in the previous section and reported in Table 2. The use of ideal profiles of individuals participating in a survey/research is common in many research papers (Gras et al., 2008; Fazio et al., 2012) and the results reported in the literature on this subject validate this method both theoretically and experimentally. A full description of the similarity index can be found in (40).

In order to analyze data we used C.H.I.C. (Classification Hiérarchique Implicite et Cohésitive) software (Markos et al., 2010). It allows associations (similarity) from a set of data to be calculated and dendrograms to be constructed in the form of ‘similarity trees’, for an easy comparison of the results. The software also
provides a level of significance for the similarity index. In fact, the similarity between two students is expressed by a percentage indicating the similarity level, i.e. the confidence assigned by C.H.I.C. to the similarity relationship between them.

The matrix that we build in order to use C.H.I.C. has the form of the one in Table 3.

**TABLE 3**

For example, let us say that student s2 used strategies 1C, 2D, 3A, 4E, 5E and 6J in his answers to the 6 questions. Table 3’s s2 column will therefore contain the binary digit 1 in the six related cells, while all other cells will be filled with 0. The last three columns represent the ideal student models described in Table 2. They are filled with 1 and 0 according to profiles defined in Table 2. C.H.I.C. works on this matrix to perform similarity analysis between students.

Figures 1, 2 and 3 show the similarity trees of students obtained with the pre-test questionnaire data in relation to each of the three ideal student profiles, Practical/Everyday, Descriptive and Explicative, respectively. In each graph students are represented by \( s_i \) (where \( i \) goes from 1 to 34) in the upper line of the graph. The ideal profile is considered as a “student” and is also placed in the upper line, like real students. The similarity trees allow us to study the similarity between each student and the ideal student profiles (at the similarity level reported by the percentages shown in the figures), and also to make evident relationships and similarities between the general answering strategies demonstrated by students.

The similarity levels between students are reported on the vertical axis. For example, in Fig. 1 the similarity between s11 and s17 is weaker than the similarity between s4 and s8, as the link between the first two students is lower than the link between s4 and s8.

**FIGURE 1**

**FIGURE 2**

**FIGURE 3**

Figures 4 and 5 show the similarity trees of the students that answered the post-test questions.

**FIGURE 4**

**FIGURE 5**

**Discussion and conclusion**

Two research questions were formulated in the introduction of this paper. We will answer them on the basis of our quantitative data analysis.

1. How can we classify the mental models that a sample of university freshmen deploy when asked to create explanations for proposed situations?

The similarity trees reported in Figs. 1 and 3 show that two student groups answer the questionnaire items using fairly definite lines of reasoning. In particular, Fig. 1 shows that 13 out of 34 students answered the pre-test questions mainly putting into action Practical/Everyday-type strategies. Going into more detail, we see that s1 shows a 99% similarity level with this ideal student profile, i.e. he always answers the questionnaire by using Practical/Everyday-type strategies. Two students, s10 and s32, show an 82% similarity level with the Practical/Everyday profile and the remaining 10 students approach the questionnaire items with strategies 61% similar to the Practical/Everyday profile. This means that they adopt different strategies (Descriptive and Explicative) in a significant number of their answers.

Four students exhibit reasoning lines at least 72% similar to the Explicative level, as shown in Fig. 3. s3 and s34 highlight 99% and 92% similarity levels with the Explicative profile, respectively, and s13 and s21 can be considered similar to this profile with a 72% confidence.
These similarity levels allow us to identify the students reported in Figs. 1 and 3 mainly as everyday/practical or explanatory reasoning holders, respectively.

On the other hand, Fig. 2 shows that one student, coded as s20, answers the test questions highlighting a clear Descriptive approach (at 88% similarity level). For 16 other students, however, the similarity analysis gives results that are not so clear. They are grouped in a cluster that highlights an overall similarity level with the Descriptive profiles of only 36%. This means that these students answered the test questions putting into action a variety of approaches, typical of people that do not have a clear line of reasoning. They answer questions by adopting mixed behavior and strategies, based on recalling real-life experience and/or memory of subjects they have studied, but also highlight the use of explicative strategies.

We can summarize saying that about a half of our student sample before instruction seem to make use of mixed modeling abilities when they are first asked to make sense of a situation belonging to a real-life field and then requested to find analogies and differences with a well-formalized law they have already studied in their general chemistry university courses. Thirteen students highlight mental models clearly influenced by common-sense lines of reasoning. Only a few students (4) in our sample are able to analyze phenomena at an explicative level.

2. Can a learning environment based on collaborative inquiry involving the presentation of problematic situations and their analysis through lab work and microscopic modeling help students to focus on the construction of explicative models of phenomena, modifying the mental models evidenced before instruction?

Our data allow us to argue that the development of a workshop based on an Inquiry approach to knowledge construction can be effective in favoring the development of explicative-type models of reality. In fact, all but one of the 34 students are classified in the post-test as mainly Descriptive or Explicative. Only s25, who was classified as similar at 61% to the Practical/Everyday profile in the pre-test, continued to apply answering strategies mainly recognizable in the same ideal profile in the post-test. In it he was classified as 48% similar to the Practical/Everyday profile.

Fig. 4 shows that a cluster of 10 students mainly used Descriptive strategies (at 41% similarity level). The remaining 23 students mainly used Explicative–type strategies, at various similarity levels, as shown in Fig. 5. These results should be compared with the pre-test results shown in figures 1, 2 & 3, where the Everyday/Practical category was much more populated (13 out of 34 students), the Descriptive one included 17 students and only 4 students mainly used Explanation-type strategies.

In conclusion, our research seems to show that before instruction many of the freshmen attending the chemical engineering graduation program at University of Palermo demonstrated mixed abilities with respect to the construction of explanations for proposed phenomena. Many students clearly show more than one view about model use, with particular reference to modeling strategies that appear inefficient for building explications of the observed/proposed situations. The results of the experimentation of an Inquiry-based course using tools able to stimulate experimental analysis, as well as modeling at micro level, seem to highlight the efficacy of such an Inquiry approach in developing and improving the students’ modeling abilities. They appear to be redirected to the construction of mechanisms of functioning and to the identification of common aspects in apparently different phenomena, which may be an indication of a general framework in which phenomena explication can develop. A significant side effect of the workshop activities is a modification of the initial propensity of students to analyze a proposed situation by first taking into account the mathematical formulas and then trying to give a physical meaning to them. After instruction many students seem to demonstrate the ability to discuss a proposed physical phenomenon by using a physical model that they perceive can be used to describe and explain the phenomenology. This often happens without having to refer to the mathematical formalism first, something that Vosniadou (1994) and Greca & Moreira (2000; 2002) pointed out as a key point to highlight a real comprehension in a particular field of physics.
Appendix

Questionnaire items and related answering strategies for each item on the basis of an a-priori/a posteriori analysis. The unforeseen strategies are in italics.

1. **A puddle dries more slowly at 20°C than at 40°C.**
   Considering all other conditions (except temperature) equal in the two cases, explain the phenomenon, pointing out what the fundamental quantities are for the description of the phenomenon and for the construction of an interpretative model of the phenomenon itself.

1A The relevant quantities are not identified.
1B The relevant quantities are not identified, but a description/explanation based on common-sense is given.
1C The relevant quantities are identified, but they are not used properly to give an explanation.
1D Only temperature is identified as relevant, but the phenomenon is not correctly described.
1E **Only temperature is identified as relevant. It is used to give a rough description of the phenomenon.**
1F The phenomenon is described by means of the macroscopic variables pressure and volume, but a microscopic model is not identified.
1G The phenomenon is described by means of the macroscopic variables temperature, energy and heat, but a microscopic model is not identified.
1H The phenomenon is described by means of a mathematical formula, but a microscopic model is not identified.
1I The phenomenon is not adequately described (by means of a mathematical formula or verbally), but a microscopic “functioning mechanism” is roughly presented in terms of “molecular collisions”.
1J The phenomenon is not adequately described (by means of a mathematical formula or verbally), but a microscopic “functioning mechanism” is presented in terms of energy exchange between molecules.
1K The phenomenon is verbally described and a microscopic “functioning mechanism” is roughly sketched.
1L The phenomenon is described by means of mathematical relationships between macroscopic quantities and a microscopic “functioning mechanism” is found.

2. In chemical kinetics it is well known that the velocity, $u$, of a reaction between two reactants follows the Arrhenius law:

$$u = A e^{\frac{E}{RT}}$$

Describe each quantity listed, clarifying its physical meaning and the relationships with the other quantities.

2A The fundamental quantities are not described and/or only examples of its application to everyday-life phenomenology are given.
2B Some quantities are mentioned, but no description of the process is given.
2C The relevant quantities are found, but only a few are described in terms of their physical meaning.
2D The relevant quantities are found but only described in terms of their mathematical meaning in the formula. No relationship between them is identified.
2E The relevant quantities are found and correctly described in terms of their physical meaning. No relationship between them is identified.
2F The relevant quantities are found and correctly described in terms of their physical meaning. Some relationships between them are identified.

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The relevant quantities are found and correctly described in terms of their physical meaning. The relationships between them are correctly identified.

3. **What do you think the role of a catalyst is in the development of a chemical reaction?**

3A A definition of catalyst is given that does not conform to the scientifically correct one.

3B A definition of catalyst is given based on an analogy with the concept of enzyme. The analogy is recalled without providing additional reasoning.

3C The catalyst is described as a substance that speeds up a chemical reaction. No additional explanation is supplied.

3D The catalyst is described as a substance that shifts the chemical equilibrium towards the products. No additional explanation is supplied.

3E The catalyst is described as a substance that speeds up a chemical reaction. An explanation is given with common language.

3F The catalyst is presented as a substance that shifts the chemical equilibrium towards the products. An explanation is given with common language.

3G The catalyst is presented as a substance that speeds up a chemical reaction. The concept is generically described in terms of energy.

3H The role of a catalyst in a chemical reaction is discussed by discussing the energy gap concept, but only in macroscopic terms.

3I The catalyst is presented as a substance that speeds up a chemical reaction. The concept is described by simply citing the energy gap concept, without any explanation.

3J The catalyst is presented as a substance that shifts the chemical equilibrium towards the products. The concept is described by simply citing the energy gap concept, without any explanation.

3K The role of a catalyst in a chemical reaction is discussed by discussing the energy gap concept, but only in macroscopic terms.

3L The role of a catalyst in a chemical reaction is discussed by taking into account the energy gap concept. The concept is explained by taking into account a microscopic model regarding collisions between molecules.

3M The role of a catalyst in a chemical reaction is discussed by taking into account the energy gap concept. The concept is explained by taking into account a microscopic model that links the energy gap concept with the molecular energy.
4. Can you give your own microscopic interpretation (model) of the Arrhenius law?

4A Everyday-life concepts are mentioned, without any correct relationship with the Arrhenius law.

4B Scientific concepts, such as energy, temperature or molecular thermal agitation, are mentioned, but they are not correctly related to the Arrhenius law.

4C The Arrhenius law is described as a mathematical function of T or E. No explanation of the meaning of these quantities is given.

4D The Arrhenius law is described as a mathematical function of both T and E. No explanation of the meaning of these quantities is given.

4E The Arrhenius law is described as a function of both T and E and the meaning of these two quantities is outlined mainly in mathematical terms.

4F The Arrhenius law is described as a function of both T and E. The physical meaning of these two quantities and/or of their ratio in the Arrhenius law is outlined.

4G The Arrhenius law is described by outlining the physical quantities involved. Collision theory is sometimes mentioned, but a clear reference to a microscopic model is not always present.

4H A generic explanation based on a microscopic model of collisions between molecules is given. The activation energy concept is outlined but its relationship with kT is not clearly presented.

4I A quantitative explanation in terms of the “collision theory” is given. A correct microscopic model is presented and the role of the activation energy and of kT is clearly expressed.

5. Can you think of other natural phenomena that can be explained by a similar model?

5A A few phenomena not related to the model are mentioned. No explanation is given.

5B A few phenomena not related to the model are mentioned. An explanation is given by using common language.

5C A few phenomena not related to the model are mentioned. An explanation is given by using mathematical formulas.

5D Some phenomena related to the model are mentioned, but these are limited to the context of the graduation program attended (chemical engineering). An explanation is given by using mathematical formulas.

5E Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account, but a clear explanation is not given.

5F Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account. An explanation is given by using mathematical formulas.

5G Some phenomena related to the model are mentioned, but these are limited to the context of the graduation program attended (chemical engineering). An explanation is given by outlining a common microscopic model.

5H Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account. An explanation is given by outlining a common microscopic model, but energy and temperature are not clearly interrelated.

5I Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account. An explanation is given by outlining a common microscopic model. The role of energy and temperature in the model is clearly discussed.
6. **What similarities can be identified in the previous phenomena? Is it possible to find a common physical quantity that characterizes all the systems you discussed in the previous questions?**

6A  No similarities are detected and questions 1) and 2) are identified being as related to a different context on the basis of everyday-life reasoning.

6B  *No similarities are detected and questions 1) and 2) are identified as being related to a different context. An explanation is given, mentioning physical quantities that are not really relevant to the correct explanation of the questions.*

6C  *A few correct similarities are found, but physical quantities that are not really relevant to the correct explanation of the questions are given.*

6D  Incorrect similarities are found on the basis of a mathematical formula.

6E  A few correct similarities are found on the basis of a mathematical formula.

6F  Correct similarities are found, but E and T are not always considered common to all phenomena.

6G  Some correct similarities are found. E or T is considered as characterizing the various phenomena, but a clear justification is not given.

6H  Some correct similarities are found. E or T is considered as characterizing the various phenomena, clearly explaining why.

6I  Some correct similarities are found. E or T considered as characterizing the various phenomena, but the relevance of their ratio in explaining the energy threshold processes is not clearly presented.

6J  Some correct similarities are found. E or T is considered as characterizing the various phenomena. The activation energy role is correctly discussed in all the phenomena mentioned, but only in macroscopic terms.

6K  Some correct similarities are found. E or T is considered as characterizing the various phenomena. The activation energy role is correctly discussed in all the phenomena mentioned on the basis of a microscopic model.
References


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**Footnotes**

1 The Arrhenius law describes the temperature dependence of the speed, $u$, of a chemical reaction: 
$$ u = A e^{\frac{E_A}{kT}} $$
where $A$ is a constant, $T$ is temperature, $k$ is the Boltzmann constant and $E_A$ is the so-called “activation energy”. $E_A$ can be described, to a first approximation, as the minimum energy that the reactants must possess in order to develop the reaction. The Arrhenius law mathematical formula contains the well known Boltzmann factor, $e^{\frac{-\Delta E}{kT}}$, an expression that is useful for portraying the behavior of natural systems that exchange energy with their environment. Arrhenius-like formulas are commonly used to describe the temperature dependence of many phenomena that need a minimum energy, $\Delta E$, to be started, or activated. These phenomena are sometimes referred to as “threshold phenomena”.

2 For each answer to a question, C.H.I.C. completely identifies a student with one of the three ‘ideal profiles’ if the student used at least one of the question-related answering strategies reported in Table II for that question, i.e., if a student used strategy 6J and/or 6K, he is classified as 100% similar (in question 6) to the ‘Explicative’ profile.

**Table 1.**

**Categories of answers to test questions.**

<table>
<thead>
<tr>
<th>Nature of answer</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical/Everyday</td>
<td>Reflects the creation of situational meanings derived from everyday contexts. The student uses other known situations to try to explain the proposed ones</td>
</tr>
<tr>
<td>Descriptive</td>
<td>The student describes and characterizes the analyzed process by finding / remembering the relevant variables and/or recalling from memory their relationships, expressing them by means of different languages (verbal, iconic, mathematic). He/she does not explain the causal relationships of the physics parameters involved on the basis of a functioning model (microscopic/macroscopic).</td>
</tr>
<tr>
<td>Explicative</td>
<td>The student proposes a model (qualitative and/or quantitative) based on a cause/effect relationship or provides explanatory hypotheses introducing models that can be seen at a theoretical level.</td>
</tr>
</tbody>
</table>
Table 2.
Ideal profiles of students and the related answering strategies for the 6-item questionnaire. Numbers refer to the item and letters to the specific answering strategy, as reported in Appendix 1.

<table>
<thead>
<tr>
<th>Everyday/Practical</th>
<th>Descriptive</th>
<th>Explicative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A, 1B</td>
<td>1C, 1D, 1E, 1F, 1G, 1H</td>
<td>1I, 1J, 1K, 1L</td>
</tr>
<tr>
<td>2A, 2B</td>
<td>2C, 2D, 2E</td>
<td>2F, 2G</td>
</tr>
<tr>
<td>3A, 3B</td>
<td>3C, 3D, 3E, 3F, 3G, 3H, 3I, 3J, 3K</td>
<td>3L, 3M</td>
</tr>
<tr>
<td>4A</td>
<td>4B, 4C, 4D, 4E, 4F, 4G</td>
<td>4H, 4I</td>
</tr>
<tr>
<td>5A, 5B</td>
<td>5C, 5D, 5E, 5F</td>
<td>5G, 5H, 5I</td>
</tr>
<tr>
<td>6A</td>
<td>6B, 6C, 6D, 6E, 6F, 6G, 6H, 6I</td>
<td>6J, 6K</td>
</tr>
</tbody>
</table>

Table 3.
Data matrix for C.H.I.C. analysis. The 34 students are shown as s1, s2, ..., s34. The three ideal student profiles are described as ‘Practical/Everyday’, ‘Descriptive’ and ‘Explicative’, respectively, and the 61 answering strategies are represented by 1A, 1B, ..., 6K (see the Appendix for more detail).

<table>
<thead>
<tr>
<th>Strategy</th>
<th>s1</th>
<th>s2</th>
<th>s3</th>
<th>...</th>
<th>s34</th>
<th>Everyday</th>
<th>Descriptive</th>
<th>Explicative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>...</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
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<tr>
<td>1B</td>
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<tr>
<td>6J</td>
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<td>...</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
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<tr>
<td>6K</td>
<td>.</td>
<td>.</td>
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<td>...</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
</tbody>
</table>
Figure 1.
Similarity tree of real student answering strategies in the test, in relation to the Practical/Everyday ideal student profile. Numbers represent the similarity levels between student clusters and the ideal profile.

Figure 2.
Similarity tree of real student answering strategies in the pre-test, in relation to the Descriptive ideal student profile. Numbers represent the similarity levels between student clusters and the ideal profile.
Figure 3.
Similarity tree of real student answering strategies in the pre-test, in relation to the Explicative ideal student profile. Numbers represent the similarity levels between student clusters and the ideal profile.

Figure 4.
Similarity tree of real student answering strategies in the post-test, in relation to the Descriptive ideal student profile. Numbers represent the similarity levels between student clusters and the ideal profile.
Figure 5.
Similarity tree of real student answering strategies at the post-test, in relation to the Explicative ideal student profile. Numbers represent the similarity levels between student clusters and the ideal profile.
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Materials from the Contemporary Physics Education Project that can be Used to Enhance Physics Classes

Gordon J. Aubrecht, II, Department of Physics, Ohio State University Marion, Marion, Ohio USA,

Abstract

The Contemporary Physics Education Project (CPEP) is a nonprofit organization founded almost 25 years ago to produce charts and other materials exhibiting areas of ongoing physics research in colorful fashion. The charts are field tested extensively before their release. There are four charts currently available. The Standard Model chart of Fundamental Interactions and Particle Physics was the first chart developed. The chart is complemented by the Particle Adventure, which is based on the web and accessible in many languages. The Fusion and Plasma Physics Chart focuses on plasmas. FusEdWeb is web-based and is accessible in several languages. The Nuclear Science chart highlights nuclides and radioactive decay and investigation of quark-gluon plasmas. The chart is complemented by the web-based ABCs of Nuclear Science. The History and Fate of the Universe chart helps students find some answers to the questions we have about where we’ve been and where we’re going. The chart is complemented by the web-based Universe Adventure, also accessible in several languages. Suggestions for how physics teachers might use the charts and other materials in their classrooms are discussed.

Introduction

Walter Michels, in his 1964 Oersted Lecture (Michels, 1964), observed that “we seem to be engaged in a conspiracy to prevent elementary students from learning that imagination, inventiveness, and intuition play any part in the growth of physics, or from suspecting that anything in the physical universe is not yet fully understood.”

The students of today still commonly see no physics beyond 1912 until they are second (or even third) year physics undergraduates. Most high school and college students are not planning to become physics majors, and can lose contact with the exploratory spirit characterizing physics research at the edges of knowledge. They may even think that physics is unchanging, totally determined, and boring.

The edges of understanding are the active areas of research, and the researchers have the most understanding about their lack of complete knowledge. People can best appreciate how little we really know about the world when they know what is known and can think about those dark continents in our minds. So we decided CPEP should bring the edges of our knowledge to the attention of those who we might consider becoming physicists and in general try to communicate the excitement of the unknown, where knowledge is incomplete to a broad public. It is in this spirit that the Contemporary Physics Education Project (CPEP) created its charts and ancillary materials.

Method

At the time of CPEP’s founding, many teachers who wished to incorporate new physics ideas had few sources of information or inspiration to which to turn. Our effort was one of the first, and one of the few organizations that continues this work. The effort was an outcome of the Conference on the Teaching of Modern Physics, held at Fermilab in 1986, and its followup meetings.

CPEP members realized that by this point in the 1980s, there was a Standard Model of Particles, and determined to create support materials that would assist teachers in considering contemporary materials for inclusion in classes. The Standard Model explains all the particle physics of the past 30 years.
At first, all CPEP members were particle physicists with a sprinkling of high school and college attendees at the Fermilab conference, but over the years additional members have added other specialties and other charts (Fig. 1).

Our method has been to create prototypes, which are then sent to teachers to be used as they wish. The teachers then give feedback, which leads to changes in the charts. The first prototype chart with a request for use and feedback was distributed by The Physics Teacher magazine, along with an accompanying article (Achor et al., 1988). Subsequent charts have been distributed through our list of active testers.

The field tests provide important information. For example, teachers at all levels who mention radioactivity generally describe α, β, and γ decays. These three decays were put in our draft chart. In doing our field test, we found students were really confused about beta-plus and beta-minus decays. We adopted the important change of including both on the chart (Fig. 2). The development and background were described in the Physics Teacher (Aubrecht et al., 1997).
Radioactivity

Radioactive decay transforms a nucleus by emitting different particles. In **alpha decay**, the nucleus releases a $\alpha$-He nucleus—an alpha particle. In **beta decay**, the nucleus either emits an electron and antineutrino (or a positron and neutrino) or captures an atomic electron and emits a neutrino. A positron is the name for the antiparticle of the electron. Antimatter is composed of anti-particles. Both alpha and beta decays change the original nucleus into a nucleus of a different chemical element. In **gamma decay**, the nucleus lowers its internal energy by emitting a photon—a gamma ray. This decay does not modify the chemical properties of the atom.

**Figure 2.** The four versions of radioactive decay as used on the CPEP Nuclear Science chart.

In addition, it was realized that teachers needed background information they could use. Originally, this was done by preprints and small books that were sold or distributed free (many are still available free through the CPEP website). The original particle teacher support preprint was revised extensively and actually published commercially (Barnett et al., 2001). However, the medium that reaches farthest is the internet, and members realized that web support material was needed. These materials were developed gradually, mainly at national laboratories, and made available as they were created.

The Particle Adventure is highly interactive and allows entrance through any of the major strands: The Standard Model; the Large Hadron Collider; accelerators and detectors; experimental evidence; and the Higgs boson. FusEdWeb is the online plasma physics course. It deals with several topics: energy sources and conversions; two key fusion reactions; how fusion reactions work; creating the conditions for fusion; and plasmas - the 4th state of matter. The ABCs of nuclear science deals with basic nuclear science: it outlines the cosmic connection; explains experiments; deals with antimatter; allows users to make a nucleus; and addresses nuclear safety. The Universe Adventure has four major sections (but access and navigation among sections is easy): fundamentals; evidence; eras; and the final frontier.
Findings

The charts have been successful in the sense that most physics departments at colleges and universities (and some high schools) have at least one of the charts hanging on their walls. Several movies that feature science have used the CPEP charts as background, as does the current hit television show Big Bang Theory. Since they were launched, the four CPEP websites have experienced millions of hits, especially so around the times that fundamental research gets media exposure, as, for example, when the discovery of a Higgs-like particle at CERN’s Large Hadron Collider was announced in July 2012.

Discussion and Conclusions

Let me use an example of how the presence of a chart in a classroom can help. When forces are introduced in many physics courses, they are mysterious. Where does the force come from? Actually, the particle chart emphasizes that forces are really interactions, and involve two bodies or agents. This is usually first seen—and misunderstood—in discussions of Newton’s Third Law.

How does CPEP help? The forces can be introduced as interactions from the first by reference to the chart: gravitational interaction, electroweak interaction, strong interaction. The chart shows on what the interaction works, and introduces the idea of exchange of particles as responsible (emphasizing the two elements). Finally, the chart provides an assessment of relative strength. The categories of particle are introduced: Leptons interact gravitationally, electromagnetically, and via the weak interaction but not the strong interaction. Hadrons are the only particles that interact via the strong interaction. (Quarks are hadrons.)

So, the CPEP chart prepares students to think of interactions between particles as fundamental—a basic physics concept that is in the context of current physics research! Even if the student does not understand the fundamental difference between the fermions and bosons, the presence of the chart can help later discovery to be less novel.

Another example comes from the fusion chart. One of the fundamental principles of physics is the conservation of energy. Energy can take on many forms, and various processes convert one form into another. Thermodynamics governs these conversions. While total energy always remains the same, after most conversion processes the amount of useful energy remaining is reduced.

The processes that convert energy into useful forms have limited thermodynamic efficiencies, typically only 10-40%. This means that typically 60-90% of the input energy becomes waste energy. Often significant waste materials are also produced. Students can see examples from common experience of generating electricity (from coal, from nuclear processes at 100,000 times the specific energy and much less waste material, and from fusion at 10 million times the specific energy of coal and even less waste material).

Furthermore, the mistaken assumption of most people, our students included, is that solid, liquid, and gas make up most of the universe and that plasmas are “out of the ordinary.” On the contrary, as a chart graph clearly shows, where we human beings live is an anomalous part of the universe, which is mainly plasma.

There are various outstanding physics problems suggested by the universe chart:

Why is there an accelerating universe?
Why is there so little antimatter in the universe?
What is the origin of mass?
Where could dark matter come from?
Why is there a huge range of masses in the universe?

The nuclear science chart introduces the observer to quark-gluon plasmas, the condition of the universe just after the big bang.

Additionally, it may be obvious that the charts, though developed independently, refer to one another.
in ways that make the whole greater than its parts. The open questions from this and the other charts could spark curiosity in our students. That curiosity is a feature that is part of most technical advances.

If we do not have citizens who are talented technically as the world becomes more technical, most of the population could retreat to superstition. Where can manufacturing industries find the technicians it needs if so few pursue a technical education? Where will projects to develop basic science find educated support staff? It is in our self interest to support education that is interesting and relevant. If our youngest citizens become technology-haters, as many of the older generation already have, there will be no way to stem technological decline.

The public must support “high tech” projects, for them to be funded. Uninformed voters, no matter how intelligent, will have no idea of the importance of scientific research, and no reason not to oppose such cutting-edge projects. The reasons for pursuit of unanswered questions will mean nothing to them. CPEP means to help these intelligent people rediscover their curiosity.

Acknowledgement

As a member of the Contemporary Physics Education Project since its founding in 1989, and chair emeritus of CPEP, I am grateful to the other members, particularly the other founding current CPEP member Michael Barnett and current president Howard Matis, for collegiality and support during the past twenty-five years.

References


Mathematical Challenges to Secondary School Students in a Guided Reinvention Teaching-Learning Strategy towards the Concept of Energy Conservation

P.S.W.M. Logman, Faculty of Science, University of Amsterdam, The Netherlands
W.H. Kaper, Faculty of Science, University of Amsterdam, The Netherlands
A.L. Ellermeijer, Foundation CMA, Amsterdam, The Netherlands

Abstract

Guiding sixteen-year-old students to rediscover the concept of energy conservation may be done in three distinct learning steps. First, we have chosen for the students to reinvent what we call partial laws of energy conservation (e.g. \(\sum m \cdot g \cdot h = k_1\)). Secondly, the students are asked to combine these partial laws into more and more general laws of energy conservation (e.g. forming \(\sum m \cdot g \cdot h + \sum m \cdot c \cdot T = k_3\)). Because a new term may always be added this process of combining laws can be continued for a long time. The result may still be only a partial law of energy conservation. A third learning step is needed in which students are to extrapolate the process of combining partial laws. If the student becomes convinced that it is indeed always possible to add an extra term to the equation when necessary, the student must now be convinced as well that the law is applicable to any situation and has thereby reinvented the general law of energy conservation. In the first two learning steps we have uncovered mathematically challenging steps which remain obscure in more traditional teachings of the concept of energy conservation. The first mathematical challenge lies in retrieving a physical law from measured data, specifically quadratic ones. The second challenge lies in combining the special cases of energy conservation into a more widely applicable case of energy conservation. In this paper we will exemplify these mathematical problems and give some possible solutions for teachers to guide students in passing these obstacles. At least partially these steps clarify the abstractness of the concept of energy and contribute to explain problems students are having in understanding this concept.

Introduction

In the existing situation in the Netherlands students’ ideas on energy in secondary education are diagnosed to be inflexible in formal examination tasks (Borsboom et al., 2008): amongst others students tend to leave some of the relevant forms of energy out of the equation when solving problems. Another flexibility problem has earlier been observed with students attending university chemistry courses on thermodynamics (Kaper, 1997): the students tended to stick to their secondary school conception of energy instead of adopting a new thermodynamic view of the concept of energy. In current education the law of energy conservation is taught as an indisputable fact detached from its scientific origin which may lead to the usefulness of the law not being immediately apparent to students (Borsboom et al., 2008; De Vos et al., 2002; Kaper, 1997). Freudenthal (1991) says knowledge and ability, when acquired by one’s own activity, stick better and are more readily available than when imposed by others. Freudenthal therefore recommends a guided reinvention approach.

We think that a process of reinvention is needed to make students realize which forms of energy are relevant to which situations and to convince the students of the general validity of the law of energy conservation (cf. Feynman et al., 1963; Joule et al., 1884). In this process the law will, as we prefer, become debatable and will no longer be an indisputable fact. Knowing the way in which the law is constructed and critically thinking throughout its reinvention may cause the students to apply their conception of energy conservation more properly and make it more susceptible for later necessary adjustments: their conception may become more versatile.
Finding an adequate balance between freedom for the students to learn and guidance from above by the teacher (cf. Lijnse & Klaassen, 2004; Freudenthal, 1991) is part of our research. We try to find this balance by posing assignments and then giving the students as much freedom as possible within the constraints set by that assignment.

As opposed to the general law of energy conservation, for the ideal gas law such a reinvention approach is used more often. The students reinvent the various partial gas laws (Boyle’s law, Gay-Lussac’s law, etc.) and combine those into one, more general law: the ideal gas law (e.g. Van Baalen et al., 2008). Guided reinvention seems possible for reinventing the general law of energy conservation as well (Logman et al., 2010, 2011). Students however may find several steps in this reinvention process mathematically challenging. Therefore we focus on which parts of mathematics a teacher should address during such a reinvention:

To which extent does a teacher need to guide students during mathematically challenging steps while students are to reinvent the law of energy conservation?

Method

We assume that for most students it’s not possible to reinvent the general law of energy conservation in one go. As a first learning step, we focus on reinventing what we call partial laws of energy conservation each with its own applicability domain (e.g. $\Sigma m \cdot h = k_1$).

In a second learning step the students will need to learn how to combine these partial laws into more and more general yet still partial laws of energy conservation (e.g. combining $\Sigma m \cdot h = k_1$ with $\Sigma m \cdot c \cdot T = k_2$ to form $\Sigma m \cdot h + 426 \cdot \Sigma m \cdot c \cdot T = k_3$). Because it remains possible that new variables will show up, this combination process does not lead to a point where one can be sure that the law is complete: the result will still remain a – possibly – partial law of energy conservation.

Therefore the students need to take a third learning step in which the process steps for extraction and combination of partial laws are extrapolated and checked whether they are always possible. In this extrapolation no new mathematical steps need to be taken. If the student concludes that these process steps are indeed always possible, in the student’s mind the law must now have become applicable to any situation and can therefore truly be called general (as opposed to partial): the general law of energy conservation is reinvented (see Figure 1).

1 If one extracts laws from experiments involving only gravitational energy one will not add the gravitational acceleration $g$ into this equation because it has no use. $k_1$ is only a constant when there is little friction and all other forms of energy are constant. It may vary over different experiments.

2 The “c” in this equation describing the mixing of various hot and cold substances denotes the specific heat of a substance but not in SI units. Historically $c$ was chosen to be 1 (kcal/kg∙K) for water. $k_2$ is only a constant when the experiment is well insulated and all other forms of energy are constant. This coefficient is different for different experiments.

3 The specific heat $c$ is here chosen to be 1 (kcal/kg∙K) for water. The factor 426 (m/K) stems from Joule’s experiment establishing the mechanical equivalent of heat. Multiplying both terms in the equation by $g$ may change the factor 426 into 4180: the specific heat of water in SI-units. The coefficient $k_3$ is only a constant when the experiment has only friction in places where the temperature is measured. Again all other forms of energy need to be constant and the coefficient $k_3$ may vary over different experiments.
Figure 1. Intended learning trajectory towards the general law of energy conservation

At this point the students should be able to apply this law to many different situations. Even in situations in which the students do not know all the terms involved we expect them to look for and reinvent the missing term to make the law complete for that specific situation (Feynman et al., 1963). If the student is able to do so he has acquired a versatile concept of energy conservation in the sense of its applicability.

During our first try-outs we focused on steps involving mathematics and observed which steps were the most problematic to the students. In our subsequent try-outs we tried to solve these problems to see whether we were able to make them less problematic. In the analysis of those steps we compared the intended reinvention of the general law of energy conservation to the somewhat similar combination of partial gas laws to form the ideal gas law to make our results more generally applicable.

In our final try-out the students received a description and data from a fictitious experiment which connects the electric potential energy of a capacitor to an already known form of energy (thermal energy) as a test. In this test the students were asked to extract a relationship between voltage and temperature and combine that law with the earlier laws. They were also asked how far this combination process could be continued and tell whether they believed a new combination could always be made when necessary. In order to answer this question we expected the students not only to perform the combination itself but pay attention to the process of combining as well.

We used three cycles to develop our educational design. The first try-out was performed by the researcher at his own school in a mixed group of 17 sixteen-year-olds. In the second try-out besides the researcher’s school five other schools were involved. In these five schools 4 teachers taught a total of 5 groups of sixteen-year-olds and 2 teachers each taught 1 group of seventeen-year-olds. In the third and last try-out two other schools besides the researcher’s school were involved concerning 2 teachers each teaching 1 group of seventeen-year-olds and 1 teacher teaching a group of sixteen-year-olds. The number of students in a group ranged from 8 to 30. The educational materials were used to replace the traditional quantitative introduction to energy. The students worked in groups of two or three students. All schools are located in the vicinity of Amsterdam.

Results and analysis

In the first try-out we encountered two major problematic mathematical steps in our approach. The first involved the extraction of a physical law from the measured data and rewriting that physical law into an easy to use notation, and the second the combination of such physical laws into one more general law.

In our learning trajectory students are supposed to extract linear and quadratic relationships. Extracting a linear law proved to be possible for the students even though the laws were not always in the notation we preferred. An example of a physical law that students came up with for mixing hot and cold water is shown in Figure 2.

---

1 The equation at the bottom right is meant to describe the general law of energy conservation including any terms as yet unknown to the students.
The extraction of a quadratic relationship from the data concerning a rollercoaster proved to be more problematic. In the first try-out only one out of eight groups managed to come up with a relationship. They did so by plotting the square of one of the measured variables against the other resulting in a linear graph. They were only able to do so after being guided by the teacher. The resulting linear graph made it easy to come up with a physical law by calculating the slope of the graph (see Figure 3).

In subsequent try-outs we decided to refer to this method as a general method used by engineers and scientists to come up with physical laws from data. In our final try-out the students received a description and data from a fictitious experiment which connects the electric potential energy of a capacitor to thermal energy as a test. In this test the students had to extract a quadratic relationship between voltage and temperature. In that test situation 28 of the 65 groups divided over four teachers did not derive a relationship at all. We assume they weren’t capable of doing so. The other groups, 37, mentioned a relationship that fitted the data. Seven of these groups however, did not show how they derived the right quadratic relationship so we are unable to say whether they were actually capable of performing the extraction themselves.

<table>
<thead>
<tr>
<th>Student’s capability</th>
<th>Extract quadratic law</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capable</td>
<td>30/65 (46%)</td>
</tr>
<tr>
<td>Undecided</td>
<td>7/65 (11%)</td>
</tr>
<tr>
<td>Incapable</td>
<td>28/65 (43%)</td>
</tr>
</tbody>
</table>

Some guidance not stemming directly from the assignment was necessary to have a better number of students extract a quadratic relationship between two variables. The students were taught a general method of extracting a physical law but still had to reinvent the particular relationship themselves. In spite of learning about the general method about half of the students remained incapable of extracting a quadratic relationship.

From the examples we showed in figures 2 and 3 it is clear that in almost all cases the notation of the reinvented laws do not show many similarities and therefore do not invite students to think about a possible combination of these laws. This extends the first problematic mathematical learning step a little further. To guide the students to a more similar notation for all reinvented laws (e.g. our intended notation in Figure 1) a discussion on which notation would be the best was held guided by the teacher. We expected that criteria given by the students for the best notation would lead to more similar notations of the various laws. The best notation meant that the law would be easy to use and would be as widely applicable
as possible in future similar problems. To start the discussion the students were asked to rewrite the reinvented laws in as many mathematically correct ways as possible. After an inventory of all possible notations the students were asked which notation would be the best:

*Teacher:* I must say there are more [notations] on the board than I myself expected. I think really all possible notations are there! I can’t think of any more. But now I have 9 possibilities.

*Student1:* Yes.

*Teacher:* Which one are we gonna choose? Who has an idea?

[...]

*Teacher:* Here I notice something strange about this notation as opposed to some other notations...

*Student2:* On both sides we have 2 variables.

*Teacher:* On both sides 2 variables. I also notice something else about that formula that... I have groups of notations in which [identifiers] 1 [and] 2 are on one side and [identifiers] 2 [and] 1 are on the other side. And I see groups, like these, in which 1 1 are on one side and 2 2 are on the other. Which would physicists, if one had to choose, which would you choose? Would you choose all 1’s on one side and all 2’s on the other or would you mix them?

*Student3:* Each on one side.

Easy to use in the eyes of the students meant not making mistakes with the formula. Using symbols made the formula easier to understand than writing the variables in full. Some students said subtractions gave them more problems than additions because in subtractions the order of the variables is essential. The teacher realized this had to do with commutative operations and asked whether they preferred multiplications over divisions as well and the students confirmed this. It may be useful for teachers to notice this and use commutative notations of physical laws in their classes.

The discussion on making the law for a rollercoaster \((2g\cdot h + v^2 = k)\) as widely applicable as possible showed several aspects. Discussing whether the zero points for the variables are free to choose, whether the units are free to choose, and whether the law can be expanded to more objects or more materials than two were held. The discussion on zero points is illustrated in the quote below. It results in adding delta’s to the notation when necessary.

*Teacher:* Read the question. Next think how many variables are in it.

*Student1:* Two variables. Three.

*Teacher:* Two variables. Yeah, actually three.

*Student2:* Three.

*Student3:* Yes. One needs to be aware.

*Teacher:* Yes, three. And does one need to take care with those? Well, let’s check all three. The \(h\), does one have to take care for the height? The zero height, where one chooses zero to be?

*Student45&6:* Yes.

*Student7:* No.

*Student8:* The zero height is zero.

*Student9:* No, that doesn’t matter, does it?

*Teacher:* If I was to put the rollercoaster on a hill, would it do the same thing, or not?

*Student1:* Yes, in principle yes.

*Student45&6:* Yes.
Student10: The zero is the bottom of the rollercoaster.

Teacher: The zero needs to be at the bottom of the rollercoaster, yes. That is well. So one has to be aware of that. But if you don’t want that, what do you need to use for that $h$?

Student7: $h$ begin.

Teacher: No, not $h$ begin.

Student5: The height you’re moving upwards.

Student10: The same.

Student7: Delta $h$.

Teacher: Delta $h$!

Student10: Delta $h$.

Teacher: Yes? And is that delta $h$ plus or minus in our experiment? That is always important as well. Using delta’s one has to be aware whether it is plus or minus. In our experiment we shot [the carts] from below upwards.

Student3: Plus.

Student4: That is plus.

Together with the students’ preference for additions and multiplications the discussions guided them to our intended notations of the various partial laws of energy conservation.

In subsequent try-outs we incorporated such a discussion into the learning material. This classroom discussion was necessary to have the students come up with the intended notation. The students were guided by being asked to make the extracted physical law easy to use and as widely applicable as possible. However, during the discussion the teacher had to guide the students to come up with the right answers.

The second major problematic mathematical step involved combining the various partial laws of energy conservation into one more generally applicable law. In both the first and the second try-out we asked what a combination of the first two partial laws would look like. Many groups came up with a direct addition of the two original laws (see Figure 4):

$$\sum m_1 h_1 + m_2 h_2 + C_1 m_1 T_1 + C_2 m_2 T_2 = \sum_m h = k_1$$

$$\sum m_1 h_1 + m_2 h_2 + C_1 m_1 T_1 + C_2 m_2 T_2 = \sum m c \cdot T = k_2$$

**Figure 4.** A group’s addition of partial laws as a suggestion for their combination

Some other groups suggested some form of multiplication of the original two partial laws (see Figure 5):

* $m \cdot \Delta h = -426 \cdot m \cdot c \cdot \Delta T$ from Joule’s experiment had been reinvented. At that point most teachers had written the partial laws like $\sum m \cdot h = k_1$ and $\sum m \cdot c \cdot T = k_2$ and students suggested adding, multiplying, subtracting, or dividing both the left and the right hand sides of these equations to combine the two laws. The first two options were the most suggested combinations of the partial laws.

WCPE 2012, Istanbul, Turkey
This transfer of mathematical knowledge to physics shows that the students were unaware that physical laws have preconditions under which they are valid. Whereas in mathematics constants are usually absolutely constant, in physics many constants are only constant under specific preconditions. Only one teacher (in the second try-out) consistently used preconditions in his discussions of the partial laws of energy conservation. For him it was easier than for his colleagues to show that most suggested combinations could not be valid for they contradicted the original partial laws under their own specific preconditions. Addition results in contradicting the law for Joule’s experiment, multiplication results in trivial equalities when either \( h \) or \( T \) equals zero. Simply adding, multiplying or performing any other mathematical operation on the two ‘constant’ terms in the two physical laws is not allowed because of the preconditions to the physical laws that in general remain silent. Rewriting the law governing Joule’s experiment into a similar notation as the other partial laws \((m \cdot h + 426 \cdot m \cdot c \cdot T = k^3)\) did however strongly suggest the right solution to combining the two original partial laws:

\[
\text{Teacher: We have found a law for lifting a heavy object and one for the mixer tap}
\]

\[
\text{Student1: Yes.}
\]

\[
\text{Teacher: We are trying to combine those.}
\]

\[
\text{Student1: Yes.}
\]

\[
\text{Teacher: Well, what do you expect to be that combination?}
\]

\[
\text{Student2: Isn’t that just what’s on the board?}
\]

\[
\text{Student1: Yes.}
\]

\[
\text{Teacher: Well, check it! With the work we’ve already done that should go much faster.}
\]

\[
\text{Student2: We checked it here.}
\]

\[
\text{Teacher: Yeah, that’s right. Keep that.}
\]

In subsequent try-outs we decided to expand our earlier mentioned discussion to include under which circumstances the reinvented law would be valid or not.

Reverse engineering the solution from the answer is easy but students will not understand how physical laws are to be combined appropriately right away, as a question of a college student on an internet forum illustrates (see Figure 6).

---

**How do you combine proportionalities - deriving the ideal gas law?**

I’m studying the ideal gas law at college but I don’t understand how they’ve derived it.

For example your given:

\[ P - \text{1N} \text{ and } P - \text{N} \]

(where \( P \) = pressure, \( V \) = volume, \( N \) = no. of molecules and ~ denotes ‘proportional to’)

It then goes on to say that if you combine these two proportionalities you get:

\[ P \sim N/V \]

I don’t understand this because if you write each of the proportionalities as equations with a constant:

\[ P = a \sim 1/v \text{ and } P = b \sim N \]

Wouldn’t you get that the ‘square of P’ is proportional to \( N/V \) when you multiply the two equations?

---

*Figure 6. A college student’s question on an internet forum.*
To generalize our findings on combining physical laws beyond the general law of energy conservation we analyze above example of combinations to form the ideal gas law. The student above shows the same transfer of mathematical rules to combining physical laws as we have shown earlier in our results without any consideration of preconditions. But in the case of the ideal gas law the situation is subtly different.

Multiplying Boyle’s law \(P \cdot V = k_5\) with Avogadro’s law \(P/n = k_6\) results in \(P \cdot V/P/n = k_7\) as suggested by the student. Addition whether or not including adding a new constant like in the case of combining partial laws of energy conservation would result in \(P \cdot V + (x \cdot )P/n = k_7\). All combinations that result from these operations are wrong. Not many teachers will address this problem in class.

The constant \(k_5\) in Boyle’s law is only a constant when \(n\) (and \(T\)) is assumed to be constant. The constant \(k_6\) in Avogadro’s law is only a constant when \(V\) (and \(T\)) is assumed to be constant. This means \(k_5\) can still be a function of \(n\) and similarly \(k_6\) can still be a function of \(V\) resulting in \(P \cdot V = k_5(n)\), and \(P/n = k_6(V)\).

Proving which combination would be the right one calls for another level of mathematics (Kaper et al., 2012) and does not seem to be an option with sixteen-year-olds. Knowing the right combination \(P \cdot V/n = k_7\) however it is easy to reverse engineer the proper function \(k_7(n)\) to being \(k_7(n) P \cdot V = k_7(n)k_5(n) = k_7\). The new constant \(k_7\) now can no longer depend on \(n\) but can still depend on \(T\), because we have been silently assuming \(T\) was constant in all experiments. Another option would be to assess suggested combinations by checking them with data from experiments.

Returning to our case of combining partial laws of energy conservation in the law \(\Sigma m \cdot h = k_1\) the constant \(k_1\) can still be a function of any variable kept constant during the experiment from which we derived the law (essentially coming down to any variable but \(h\)). Similarly in \(\Sigma m \cdot c \cdot T = k_2\) the constant \(k_2\) can depend on any other variable but \(T\). In the right combination \(\Sigma m \cdot h + 426 \cdot \Sigma m \cdot c \cdot T = k_3\) the constant \(k_3\) does not depend on either \(h\) or \(T\) anymore. Apparently the functions need to be \(k_3(T) = -426 \cdot \Sigma m \cdot c \cdot T + k_3\) in which \(k_3\) can no longer depend on \(T\) (nor \(h\)). Again proving the right combination from the partial laws would call for another level of mathematics (Kaper et al., 2012).

For education we can now choose from two possible approaches: reverse engineering from the right solution or assessing possible combinations with measured data. The first approach does not agree with our choice for guided reinvention because the solution needs to be known beforehand and is therefore not reinvented.

That is why in our subsequent try-outs we decided to use the second approach. First from a demonstration of Joule’s experiment the law that governs it was reinvented in a classroom discussion guided by the teacher. Next the students were asked to rewrite that law into a similar notation as before \((m \cdot h + 426 \cdot m \cdot c \cdot T = k_4)\). This notation suggested to most students the right combination, \((\Sigma m \cdot h + 426 \cdot \Sigma m \cdot c \cdot T = k_4)\) which was subsequently checked with the data and the reinvented laws governing the earlier experiments to see whether the new combination did indeed incorporate all the earlier laws as well as the law describing Joule’s experiment.
Teacher: What was the formula again that we discovered during lifting? In the end?
Student1: m times h, wasn’t it?
Student2: Yeah, m times h.
Teacher: This, right? [Writes $\sum m \cdot h = \text{constant}$ on the board]
Student3: Yes.
Student2: Yes.
Teacher: Is this one very different [from the new combined formula]?
Student2: No.
Student3: You just...
Teacher: What did we find for the mixer tap?
Student3: Well... I don’t know.
Student4: c times m1 times T or something like that.
Student2: That was eh...
Teacher: I hear someone mention it. [Writes $\sum c \cdot m \cdot T = \text{constant}$ on the board] Is this one very different?
Student4: Well, no...
Teacher: Well, it is a little.
Student5: Eh, something needs to be added to it.
Student1: Yes, it only needs 426 in it.
Teacher: Is that allowed? Was I allowed to write 426 on both sides?
Student4: Yes.
Students1,2&6: Yes.
Teacher: Yes, that’s allowed, isn’t it? It would be nonsense again, like he said. [...] I can multiply by 426 but why would one do so? Well...
Student2: Than it becomes more complicated.
Teacher: Than it becomes more complicated, but now I can suddenly describe Joule’s experiment when I include the 426, only when I include that 426 in it, does it describe Joule’s experiment as well. If I don’t add it, right, than I get that the temperature would rise a lot. If I drop something one meter the temperature would rise a degree Celsius as well. That is not the case. That’s why the 426 is in it.

We hope that after combining the first two partial laws the students can get the hang of this approach and apply it to further expansions of the law themselves.

In our final try-out the students received a test containing a description and data from a fictitious experiment which connects the electric potential energy of a capacitor to an already known form of energy (thermal energy). Subsequently the 65 groups were asked to extract a law from that data and combine this new law with the earlier combined laws. Out of the 30 groups that managed to extract the quadratic relationship between voltage and temperature 8 groups weren’t able to combine this law with the earlier combined laws at all. Five groups combined the extracted law in a wrong way whereas 17 out of those 30 groups did manage to come up with the right combination. One of the groups that earlier on in the learning process did not show the derivation of the extracted law now managed to combine it in a proper way. So in total 18 out of the 65 groups managed to combine a new physical law into the equation.
Table 2. Student’s capabilities in combining partial laws of energy conservation

<table>
<thead>
<tr>
<th>Student’s capability</th>
<th>Combine laws (all students)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capable</td>
<td>18/65 (28%)</td>
</tr>
<tr>
<td>Undecided</td>
<td>2/65 (3%)</td>
</tr>
<tr>
<td>Incapable</td>
<td>45/65 (69%)</td>
</tr>
</tbody>
</table>

We should not expect those students that were incapable of extracting the quadratic law to take the next learning step. Only looking at those students that succeeded in extracting the quadratic law shows that even for those students the combination step was still quite a big step to take.

Table 3. Student’s capabilities in combining partial laws of energy conservation limited to those students that were capable of extracting the quadratic law

<table>
<thead>
<tr>
<th>Student’s capability</th>
<th>Combine laws (students capable of extracting quadratic law only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capable</td>
<td>17/30 (57%)</td>
</tr>
<tr>
<td>Undecided</td>
<td>0/30 (0%)</td>
</tr>
<tr>
<td>Incapable</td>
<td>13/30 (43%)</td>
</tr>
</tbody>
</table>

Conclusion

Reinventing the general law of energy conservation is not possible without conquering some big mathematical obstacles, the two most important ones being extracting a quadratic relationship from experiments and combining partial laws of energy conservation into more general laws of energy conservation.

Finding an adequate balance between freedom for the students to learn and guidance from above by the teacher (cf. Lijnse & Klaassen, 2004; Freudenthal, 1991) is part of our research. We try to find this balance by posing assignments and then giving the students as much freedom as possible within the constraints set by the assignment.

However, within the constraints set by the assignments many students did manage to take the first learning step of extracting a physical law from measured data without extra guidance as long as the relationship was linear. Using an extra form of guidance, being a general method of extracting a physical law by linearization, about half of our groups of sixteen-year-olds were capable of overcoming the first problematic mathematical step of extracting a quadratic relationship between variables themselves. The method consists of plotting various functions of the two measured variables until a linear graph is found.

Establishing the domain and preconditions of a physical law is not a natural thing for our students to do. We guided them through this process by a classroom discussion on which notation would be the easiest and most widely applicable. This discussion guided by the teacher concerned the following subjects:

- easy to use notations,
- zero points for involved variables,
- units to be used in the law,
- expansion to more than two objects or substances, and
- preconditions on the law.

- It was interesting to notice that students preferred commutative notations of physical laws whereas that is not always the case in physical laws as taught.
The preconditions on the law are especially important when combining partial laws to establish which possible combinations can be discarded and which others can be assessed experimentally. Guidance to combine partial laws can be done either by reverse engineering the partial law from the more general law or by rewriting physical laws stemming from crucial connecting experiments (like Joule’s experiment) and subsequently testing the resulting possible combination by experimental data.

In traditional teaching the reverse proof is often used to ‘explain’ physics (e.g. Van Baalen et al., 2008). One has to be aware however that this approach may leave students wondering how such combinations are performed as shown in the example of the college student wondering about the combinations of Boyle’s and Avogadro’s law.

In our approach using an assessment of suggested combinations the process becomes more apparent even though a mathematical proof for the eventual solution is avoided. By showing the students crucial connecting experiments and rewriting the resulting physical law similarly to the partial laws in question (e.g. \( m \cdot h + 426 \cdot m \cdot c \cdot T = k_3 \)) we were able to suggest an appropriate combination of partial laws (\( \sum m \cdot h + 426 \sum m \cdot c \cdot T = k_3 \)). This combination could then be assessed using the data from all connected experiments.

After guiding the students through two of such combinations about a quarter of our groups of students showed they were capable of combining a new partial law into a more general law themselves.

Clearly we underestimated the mathematics behind a reinvention of the law of energy conservation. For simple linear equations guided reinvention combined with a context-based approach should be possible for sixteen-year-olds. Perhaps the extraction of quadratic relationships and the combining of partial laws should be postponed to later classes. Another option would be to guide the students through more combinations before they are asked to attempt one themselves or pay more attention to the involved mathematics prior to our intended learning trajectory.

It is clear that school physics differs from school mathematics in the process of combining physical laws due to the preconditions on such laws. This difference is an addition to earlier described differences between mathematics and physics by Ellermeijer (2003) and Heck (2001). Students are much more used to the mathematical approach than the physical approach to combining equations and transfer mathematical rules to physics unaware of the preconditions under which physical laws are valid. To help students understand these differences better, preconditions deserve explicit attention in class. Besides that it appears that keeping every other variable constant in experiments has become too silent an assumption and in that way conceals those preconditions from the students.

The two mathematical steps hidden in traditional teaching show some of the abstractness behind the energy concept and may explain part of the difficulties students have in seeing the usefulness of the concept and in applying it to various situations.

References


Equivalence and Equivocation: Revisiting the Teaching of Energy

Corrado E. Agnes, Department of Applied Science and Technology, Polytechnic School of Engineering, Turin, Italy.

Abstract

A certain consensus is growing in the science teacher’s community toward the early and informal introduction of the so-called primary physical quantities. They are energy and the “conjugated variables” of the classical thermodynamics, the extensive (former “exchange”) variables and the intensive (former “contact”) variables, reasonably renamed “quantities” and “intensities”. At the beginner’s level energy is introduced with the question: What have in common hot water, electricity, bread …? The relation between the flow of these substances (reasonably renamed “energy carriers”) and energy is established with the rule: energy never flows alone. This leaves energy as the only “idea” between many “things”, and I believe it is important to supply from the beginning some kind of definition of energy. Although during the learning process the “things” become formalized physical quantities, that is “ideas”, and conversely energy becomes an important “thing” in the real world. Taking on the “what have in common hot water, electricity, bread …?” argument, the definition comes from the comparison of the energy carriers. Think of a process during which electricity and heat both flow in and out of a physical system. For example a thermo – electric device, now considered as a device which compares electricity and heat. This triggers ancient bans because heat and electricity appear to be incomparable quantities, “incommensurable” is the word used. Well, the comparison is made possible by the discovery – invention of energy, a function of electricity and heat which completely characterizes the physical system under consideration, precisely mapping the possible exchanges and equivalences. Three features of the proposed approach are worth emphasizing. First the theoretical settlement which can be considered a simplified version of the general dynamics approach of classical thermodynamics. The set of the energy carriers is shown to be a righteous equivalence class, following the mathematical rules for equivalence, from which the definition of energy is firmly grounded, as the quantity discovered – invented to compare the quantities exchanged between physical systems. Second the way demonstration experiments, both qualitative and quantitative, are easily implemented in the didactic practice. Chains of energy transfer experiments, with the same final output, enable to ground the relation between the intensity of the carrier current, the driving difference of the physical process, and the intensity of the energy current, as we have seen in many examples of the recent literature on experiments. Third the proposed model for mental representation of physical phenomena, the substance – model, seems to fit well into the contemporary cognitive research for science education.

Keywords: Energy, Energy forms, Equivalence

Introduction

Waiting for hurricane Sandy, I had to be ready to write this article by hand (in gloves) at candle light, and the fact that a few meters hill prevented all these inconveniences, added an unexpected kind of embodiment to my subject. Actually the contemporary debate on climate change and global warming (Fig.1) is giving highly emotional contents to the public understanding of energy. The science and technology challenge for environment friendly energy sources have at least brought some benefits in terms of interest toward almost all the natural sciences disciplines. But, on the contrary the popularity of physics among students is low and the enrolment declines, as any statistics laments.
I believe a little self-criticism is needed here, looking for the reasons in the very house of the teachers. Take indeed as typical the media coverage of the climate change discussion. Only two words from the physics vocabulary are being used: energy and temperature. And most textbooks use only these two physical quantities to explain thermal phenomena. But with only two quantities it is awkward and inapt to teach any area of physics. Thermodynamics without entropy, mechanics taught almost without momentum, are unnecessarily complicated, as well as chemistry without the chemical potential. Energy is at the centre of the stage of all natural sciences since many years, but dressed as it was at the end of the XIX century after its tortuous and difficult discovery. It became the star of the physical quantities during the tumultuous developments of modern physics, but at the cost of losing its roots in classic thermodynamics, so that the deficiencies of its didactic and cultural layout are still evident. For example the idea of “energy forms” was an essential weapon when energy and energy currents were almost unknown, but has become an infelicitous cut short for the above mentioned need of three physical quantities for any “form of energy” be really understood.

Moreover the contemporary science teacher’s community faces the problem of teaching energy in an interdisciplinary way. To make this goal really achievable, we need to shape the teaching of energy ready to be used not only in physics but also in biology, chemistry and the natural sciences.

We need new words, and more words again to teach physics with the minimum amount of mathematics, so that we could convey the cultural heritage of the impressive synthesis of the physical science made by J.W. Gibbs, a century old but itself still almost unknown outside specialist’s science. So let’s begin with the words science uses to represent natural phenomena

1. Nomina Non Sunt Consequentia Rerum

When we hear the words “cell, gene, chromosome”, we know we are within biology; and “element, bond, valence” belong to chemistry. The “physical quantities” are the “reserved” words of physics, but to understand what they serve for and what they really convey, let’s take the paradigmatic example of “length”. When we say that a stab is 3 meters long, we mean that another stab (the standard stab in Paris) can be put three times from the beginning to the end of our stab. With the word “length” we express a relation between objects, fairly general to become the property of the single objects. Physical Quantities are ideas born in the mind of humans, not things from the outside world. Through the process of measurement and the expression of the result with a number, physical quantities become mathematical variables, and real objects become “physical systems”, undergoing processes which are collection of states. The state of a physical system is described by the values of all the variables characterizing it, together with their accuracies. However this does not mean that mathematical formulas are the “language” of physics. Contrary to the many very authoritative opinions, I believe the formulas are the last step, the coded formulation of a thinking process, expressed in the very concise mathematical symbolism.

The first tool I’ll use for the ambitious task of revisiting the teaching of energy is the idea that some physical quantities are to be considered, for the understanding and the teaching purpose, more important than others, so that I decided to use the word “primary quantities” for them.²

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1 The original quote, by which the name of something could embody and reproduce its essential nature, was purposely negated to emphasize the main thesis of the section, which is underlined.

2 This has nothing to do with the distinction between “fundamental” and “derived” physical quantities, where legal issues with important consequences in real life are at stake.
As some words are more pregnant and meaningful than others, so that they can describe many different situations, the primary quantities synthesize centuries of observations and quantitative thinking about their metrization. Like the words from the philosophical vocabulary, none is simple, but when they come to be learnt, they open and widen the thinking horizon.

I believe it is regrettable that instead of acknowledging the real conceptual difficulties and enquiring about them, the traditional didactic approach prefers a sort of censorship, ignoring them or hiding them in mathematical formulas. With the recipe: “learn mathematics because it is the language of physics”. Does this remind the way we all were taught?

2. Engineering the Teaching of Physics

The primary quantities are energy, entropy, linear and angular momentum, electric charge, amount of substance ...etc, the “exchange” variables of classical thermodynamics. Which is enough for physicists to understand their importance, but let me add a few details to sustain their teaching utility. They are additive in the sense extension is, they are closely related to the volume in the sense of having a density and filling it or flowing in and out of it. They have a current and the currents are additive too. Summing up they are “substance – like” in the sense that it is easy to represent them as matter, a kind of stuff which can be exchanged between physical systems. To each primary quantity corresponds an “energy conjugated variable”. They are temperature, linear and angular velocity, electric and chemical potential ...etc, the former “contact variables”. They can also have a rich vocabulary of meaningful words describing them. They are intensive, they belong to a point, so that in a region we speak of the mean value. They are not additive in the sense that when two physical systems having the same value of an intensive variable are brought together into one system, the intensity remains the same. We can say they are subtractive in the sense that a current of the quantity can be imagined as driven by the differences of intensity. Their dependence on time has the characteristic of a rate of change not that of a current. They are simple to be measured because they indicate the equilibrium of the following fundamental process: the exchange of a quantity between two physical systems until the values of the intensities become equal.

There is a simple paradigmatic example, and it is the amount of water in a container and its level.

Moreover primary quantities and intensities give us the way to recognize a common structure between the physics chapters, which got hidden during the twisted thread of research.

But the easy way in which analogies are built between them is grounded in the generality of the underlying model, the “substance – model”, which was worth summarizing because it entered the practice of continuum physics without being recognized as such. But both analytical mechanics and thermodynamics use it, and recently it has attracted the interest of the researchers in psychology of education, because with the basic concepts of “quantity”, “intensity” and “force” it seem build a “Force Dynamic Gestalt” [Fuchs 2010] for the thinking of the human mind and so being the natural model for science education.

Energy Forms and Energy Carriers

3. Existence and Exchange Forms of Energy

There are two different methods to categorize energy into different forms: one allows stored energy (energy contained in the system) to be assigned a form, and the other classifies exchanges of energy. The first method leads to kinetic energy, potential energy, internal energy, elastic energy, the “existence” forms of energy; the second one leads to electric energy, chemical energy, heat, work, the “exchange” forms of energy. [Falk , Ruppel 1976].

The above stated need to have at least three quantities to describe the change of the state of a physical system is expressed by the so-called Gibbs Fundamental Form [Falk 1968], which can be considered the definitive version of the first law of thermodynamics, and states the relation between the changes of the energy of a system and the changes of the variables specifying the state of the system:

\[ dE = vdP + TdS + Udq + \mu dn + \ldots + \lambda dQ \]
where, $T$ is the absolute temperature, $S$ is the entropy, $U$ is the electric potential, $q$ is the electric charge, $v$ is the velocity, $P$ is the momentum, $\mu$ is the chemical potential, $n$ is the amount of substance, and $Q$ the generic quantity with $\lambda$ its "level". The intensive variables determine how strongly the energy changes when the extensive quantity changes. Now one can imagine any exchange of energy as the result of a current flowing into or out of the system in question. It follows that an energy current can be written as a sum:

$$I_E = v F + T I_S + U I + \mu I_n + \ldots + \lambda I_Q$$

The presence of many more terms than the ones written explains why was it so difficult to assess energy. If we compare the Gibbs Fundamental Form with the traditional expression of the first law, we understand the main didactic problem with the one word, one symbol exchange forms work $W$ and heat $H$. The subtle point is that neither of them can be described as contained in physical systems, so that beginners students are dragged into a logical rollercoaster of something which can enter the system but not stay there without mysteriously changing from one form to another. The balance is made easier following closely the quantities, so that we no longer need the "theorem of work and kinetic energy" to understand that $v dP$ is the exchange form for movement energy, when both momentum and energy are accumulated in the body, distinguishing it from the work $F dl$, when momentum is not accumulated but flows in and out of the body.

The integration of the Gibbs Fundamental Form, when possible, gives the expression of the energy as a function of the primary quantities, and it will completely describe the system: in mechanical systems, this kind of a function is called the Hamiltonian, and in thermal systems, it is called thermodynamic potential. In a whole range of familiar systems this function decomposes into a sum of terms where each term is independent upon variables which do not appear in the other terms of the sum. The individual terms can each be given their own name, and these are the "existence" forms of energy. It is always worth refraining from giving specific names for the variable a quantity depends upon, as well as giving specific names for ranges of values of a variable, but in the case of energy it has a twofold major drawbacks. First it gives this form of energy some kind of existence of its own and makes the energy function disconnected from the system to which the energy belongs. Second it gives the misleading impression that separated terms of the energy function be separated parts (sic!) of the system. Enhanced by the superfluous expression "internal energy" for the energy of the system, but ominous of the ambiguities of separating the internal energy in parts: which part of the internal energy of a gas is kinetic, potential, chemical??[Job, Herrmann 1996]

4. Equivalence

Coming to the equivalence of the energy form, which is in my opinion the weakest part of the traditional approach, I'll use the word "equivalence" in the everyday language meaning $^1$ "corresponding or virtually identical especially in effect or function". It is worth noticing that it is used with the same meaning in the mathematical discourse, when comparing entities which are different but equal in the feature which is considered relevant. For example triangles having different sides and angles, different form indeed, but the same area. As an example from physics take the image for energy saver bulbs (Fig. 2), where what is equal and what is different is very precisely (exceptional for a commercial indeed!) announced. Moreover this meaning is not in open contradiction with the precise mathematical definition of an equivalence relation, which I will use extensively in the positive part of the article.

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$^1$ Merriam – Webster on line dictionary “equivalence” meaning 3

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WCPE 2012, Istanbul, Turkey
Exactly this meaning was used to state the first law of thermodynamics, and can historically be traced down to the Joule experiment (1843). “The thought that the amount of work necessary to the generation of a specific amount of heat could depend on temperature could not be addressed with that simple experimental set up. It was known at the time that heat generated at high temperature could be used to perform more work than heat generated at low temperature. Apparently heat is more valuable at high temperature than the same amount of heat at lower temperature, more work is necessary to produce the same amount of heat at higher temperature” [Job, Lankau 2003].

That clearly amounts to say that heat and work are not equivalent under the mathematical rules of equivalence. But also under the rule of common sense stated above.

5. Equivocation

The deficiencies of the equivalence of energy forms are simply stated in the following way: the previous statement is valid for every exchange energy form. Two equal amounts of the same energy form are not equivalent, according to the above mentioned common sense meaning. Unfortunately it is the very meaning all users of the term want to communicate for teaching and understanding energy.

To simplify the argument, let’s consider ideal reservoirs of a generic energy form, that is a physical systems which can supply and receive any amount the generic quantity \( Q \) together with the amount of energy \( E \) without changing its “level” \( \lambda \), its intensive variable, so that the relation \( E = (\lambda - \lambda_0)Q \) holds for any finite transfer process, where \( \lambda_0 \) is a fixed reference level.

If we look simply at the formulas we see a product, which can be obtained with a small \( Q \) and a big \( \lambda - \lambda_0 \). Or vice versa. It seem the same as the example of equivalent triangles, but this is a good example to remind us that there is more in physics than mathematical formulas.

Now let’s go back to the highlighted statements, and prove them first in thermodynamics, and then understand why they hold in general.

“heat generated at high temperature could be used to perform more work than heat generated at low temperature” because \( H=TS \) so that, for given \( H \), \( S \) is larger at low temperature and because the final destination of any amount of entropy is the depository at room temperature \( T_0 \), the amount of energy which cannot do work is \( E = T_0S = T_0 \frac{H}{T} \), which is a decreasing function of \( T \).

“more work is necessary to produce the same amount of heat at higher temperature” because any amount of heat at room temperature does not need any work at all (but it is completely worthless, apart from heating colder things, which of course needed work when they were cooled). On the contrary the same amount of heat \( H=TS \) at higher temperature needs (and gives in the reversed process) the supplementary work

\[
W = (T - T_0)S = (T - T_0) \frac{H}{T} = \left(1 - \frac{T_0}{T}\right)H
\]

which is an increasing function of \( T \). Welcome to the discussion S. Carnot, Master of Engineering!

One could object that these results hold only for thermal energy, because the environment temperature is the “shifted” representative of the “absolute” zero of temperature, and the involved quantity is entropy, the cause underneath all dissipative processes. On the contrary it is a very general result which holds for all the forms of energy. As well as thermal energy at different temperatures, hydraulic energy at different pressures, mechanical, gravitational, electric or chemical energy at different potentials are not equivalent, they can be “only” equal.

Literally reversing the common sense meaning of equivalence.

The reason is more fundamental than resistance and dissipation, which can be considered at most aggravating circumstances, as shown by the fact that the above calculations are for ideal processes. The reason is the existence of natural boundaries for the values of intensive physical quantities (all of them!)
[Agnes 1996]. Also atmospheric pressure is the “shifted” representative of a “minimum” value, and the “relative” zeroes of all the other potentials, which are theoretically “shift able”, are no less effective in posing fundamental limits on the transfers of energy and the involved primary quantity.

Concluding, what is equivalent in the transformation of two equal amounts of energy forms is hidden by the term form, and to made it explicit we have to look to the quantity. As soon as we identify the hidden physical quantity, we realize that it has a different “exchange value” depending on the variable assigning the level. The value of the intensive variable tells us how much the quantity is “charged” with energy, a metaphor for the mathematical properties of a derivative.

The basic teaching difficulty about energy forms is to speak of one quantity, the energy, being equal and different at the same time, and I hope to have shown that the term equivalence is part of the problem and not of the solution. So that to speak of “energy carriers”, intending to speak of the quantity which is transferred together with energy, instead of energy forms, seems to dispose of the problem.

The Discovery – Invention of Energy

6. The Touchstone Quantity.

To recover the conceptual strength of the mathematical equivalence we need only to realize that the primary quantities form a righteous equivalence class and base on it a very simple idea to introduce energy. Because I believe my proposal applies to all levels of the physical discourse, I’ll formulate it using terms from the common language and examples from everyday life. At beginner’s level for children [Falk, Herrmann 1981], energy is introduced with the question: what do they have in common hot water, electricity, bread ..etc, and reinforced with the rule: energy never flows alone. Taking on the “what have in common” argument, the definition – invention of energy comes from the comparison of the energy carriers. Think of a process during which electricity and heat both flow in and out of a physical system. For example a Peltier element (Fig. 3), a thermo – electric generator, now considered as a device which compares electricity and heat. This triggers ancient bans because we are dealing with the so called “incommensurable quantities”, but the comparison between electricity and heat is made possible by the discovery – invention of energy. A function of electricity and heat which completely characterizes the physical system under consideration, precisely mapping the possible exchanges and equivalences, as it will be detailed later when introducing its Gibbs Function. What I want to explain is the generality of this procedure, starting with an analogy from a very different field, Economics. The “exchange value” of goods is a paramount example of a problem similar to the one we outlined, about the “value of exchange” of the physical quantities”, and its solution is well known. The discovery – invention of “money” to compare the value of different goods. This view is supported by the fact that goods form an equivalence class under the operation of exchange (barter). Like what happened in primary school when we were banned to add apples with pears. Then (the invention – discovery) of size, weight, “piece” of fruit” made the comparison possible: they were equivalent in respect to those physical quantities.

The true point of the discovery – invention of physical quantities is that they permit to compare “different physical systems” under the category of equivalence. This view of physical quantities together with what we learnt about equivalence finally explains the somehow mysterious subject of the “physical dimensions”: physical quantities with the same dimensions are “equivalent” different physical quantities, so that we can add and subtract them. We call the very special situation when the identity of two different physical quantities is stated and confirmed, a law of nature! [Agnes 1996]. Take for example the seldom written relation for the energy balance \[ \frac{dE}{dT} = I_E \]

it says that the change of the energy contained in a volume is equal to the current of energy flowing in or out through the surface of the volume. The physical quantities “energy time rate of changein the volume” and “energy current” are different in the mathematical structure, they belong to different space parts, and...
can be equal if and only if no energy is created or annihilated within the volume. Energy can change only by addiction or subtraction from another system. This is the conservation of energy. Taking an example from everyday's life in the classroom, when a pupil asks to go to the bathroom, the numbers of pupils in the class remains conserved, but it is no longer constant!

7. Energy Flow Diagrams

The previous argument was made possible by the fact that classical thermodynamics can be formulated according to a general system theory [Fuchs 2000]. A very useful consequence of it is the possibility of describing whatsoever flow according to in , out and contained items, as it is well known from the Data Flow Charts of Informatics. The energy and energy carriers flow fit particularly well in this picture, giving us the possibility to describe physical processes and devices in a very synthetic and meaningful way (Fig 4).

I'll use energy flow diagrams for well known technical apparatuses to show that the set of the energy carriers constitute a righteous equivalence class, following the mathematical rules for equivalence, from which the definition of energy is firmly grounded, as the quantity discovered – invented to compare the quantities exchanged between physical systems.

From the mathematical definition of Equivalence Relation, which is based on three properties: It must be Reflexive (A ~ A), Symmetrical (if A ~ B then B ~ A) and Transitive (if A ~ B and B ~ C then A ~ C), we can design a collection of demonstration experiments to show that the set of energy carriers build an equivalence class under the physical processes of “change of carrier”. The examples deal with the primary quantities heat electricity and rotation, common words for entropy, electric charge, angular momentum.

The property of reflexivity corresponds and is demonstrated with the technical devices known as transformers. Because they operate the conversion of a quantity/current from/to high – low potential should more significantly called Converters. In addition to the well known Electrical Transformer, there are Heat Transformers [Herrmann 2009], Angular Momentum Transformers (Gears) (Fig 5).
The property of symmetry corresponds and is demonstrated with the many technical devices whose operating can be reversed. They are known under many different names, and they could be more significantly named energy unloaders or transloaders. All possible combinations are realized practically: my examples are the of the Peltier device, which works as an electrical heat pump or a thermo–electric generator, the dynamo and the electric motor, the Stirling machine and the historical Joule experiment (Fig 6).

The property of transitivity corresponds and is demonstrated by the connection of the devices one to another, in a sense a chain rule making a diversion in the flow of energy. The fact that no new examples are needed is a clear indication that we are going in the right direction. The same devices used to demonstrate the symmetry of the heat–electricity–rotation equivalence demonstrate the transitivity both in the forward and in the backward rotation–electricity–heat direction. In the picture there is transitivity demonstrated and concentrated in the commercially successful didactical Pasco gadget (Fig 7).

8. Embodiment and Experiments

I believe in the general “gestalt” based on quantity, intensity and “force” because of the comfort in doing natural sciences with (primary) quantities, intensities and energy. And the easy way in which physical quantities are introduced beginning with perception and feeling, what contemporary education psychology now calls “the embodiment of concepts”, is not secondary reason for that comfort. Think how different is the feeling of “about 2 km” when it refers to the extensive distance to the station and to the intensive height drive for a possible fall. The same kind of difference between a building about 2 km high and a 1776 meters tower, this time making emotional appeal to very different quantities and intensities.

Back to the classroom experimental aspect of science teaching: I believe it has to go through three levels of laboratory, embodiment, qualitative and quantitative experiments, which are easily implemented in the didactic practice of the proposed approach. A collection of demonstration experiment made according this approach can be found on you tube [D'Anna, Rosenberg 2010].

Let’s consider only the relation between the intensity of the carrier current, the driving difference of the physical process, and the intensity of the energy current. At the primary school level it is introduced with the example of the waterfall and its rule: a waterfall is more powerful the larger the current, the deeper the fall. Demonstration qualitative experiments can be devised for intermediate students and quantitative experiment for high school students. The experimental strategy is always the same: chains of energy transfer with the same final effect demonstrate the double proportionality $I_E = (\lambda - \lambda_q) I_Q$.

In the experiment sketched in the illustrations [D'Anna 2007], current and potential difference are varied through an electric heater immersed in water, by connecting parallel and series resistors, so that the increase of temperature during time is the same. The apparatus is shown in (Fig. 8). The table sums up the experimental observations (Fig. 9).

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1 Architect Daniel Libeskind’s “Freedom Tower” at Ground Zero New York City.
The two graphs (Fig. 10, 11) show the steady increase for fixed current or fixed potential difference.

<table>
<thead>
<tr>
<th>Tasso di aumento temperatura (°C/s)</th>
<th>Intensità corrente $I_0$ (A)</th>
<th>Differenza potenziale $\Delta \phi$ (V)</th>
<th>Tasso di aumento della temperatura $\Delta T/\Delta t$ (°C/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.89 $10^{-3}$</td>
<td>2.82</td>
<td>2.96</td>
<td>8.35</td>
</tr>
<tr>
<td>8.93 $10^{-3}$</td>
<td>2.00</td>
<td>4.23</td>
<td>8.46</td>
</tr>
<tr>
<td>8.96 $10^{-3}$</td>
<td>4.01</td>
<td>2.11</td>
<td>8.46</td>
</tr>
</tbody>
</table>

If, as I hope, we are on the eve of a science teaching revolution, it has been made possible by two technological revolutions, the on-line sensor technology and the computer modeling software. I see both as a confirmation of the soundness of the proposed method. Because on one side the software modeling too deals primarily with quantities and currents, on the other side the sensor technology widens the perception and fits well in the cognitive approach to education. The figure (Fig. 12) shows the program and the graph used for the heating experiment, made with the modeling software “Stella”™.
9. Identification of a Physical System

The procedure we used to introduce energy told something unexpected about the general nature of physical quantities, namely their general equivalence meaning. But proceeding along the same line of thought another unexpected interpretation of energy is coming, which I hope can be usefully implemented. The Gibbs Fundamental Form of a physical system is a differential mathematical relation from few variables to many, many physical systems. In the very few cases in which it can be solved as a function of the primary quantities, it completely defines the physical system and precisely maps the possible exchanges with other physical systems. This result from classical thermodynamics permit us to say that the energy function identifies without ambiguity the physical system, defines its identity. Which physical system increases its volume if we supply heat, add electricity, put more substance inside, make this substance chemically react, take away some upper water, change the substance of the surrounding atmosphere?1 A physical system is in a sense dynamically characterized by the totality of all the possible exchanges with other physical systems, as well as chemical substances could be represented and in a sense defined by the totality of the possible “reactions”, organisms by the totality of their “interactions” with the environment. But the analogy goes well beyond the borders of natural sciences, for example to learn to know a person means identify what s/he likes – dislikes, that is whatever things or emotions are a welcome inflow, or a welcome outflow. The contemporary discourse on “group identities” uses the same approach, defining the identity starting from the cultural exchanges. There is a trivial but powerful reason why all this can be useful for science teaching, and it is that we have words everybody understands because they are the words of human communication. And the elevated reason is that only when metaphors from the natural sciences enter and mix with metaphors of literature, philosophy, art ... etc, we can be sure of effectively contributing to the one human culture, as the original meaning of culture soil indicates.

But the technical reason to use Gibbs Functions as Identifiers of physical systems is that they are a perfect match for the “forms of existence of energy”, whose limited utility in the traditional meaning I showed above (3). They are almost identical as mathematical expressions but being strictly associated to the physical systems they convert the physical discourse from abstract to concrete, and it works too with “ideal systems” like the reservoirs we used in the argument of equivalence (5).

I hope the examples of the very few system for which a closed form for the Gibbs Function can be written, will be convincing. \[ E = \frac{p^2}{2m} \] is not the formula for the kinetic energy, but the Gibbs Function of the system Moving Body. The ID of the system fully addresses energy and all its variables, not only one. Similarly \[ E = \frac{q^2}{2C} \] is the Gibbs Function of the system Electrostatic Field in a Capacitor; \[ E = \frac{1}{2}kx^2 \] is the Gibbs Function of the Elastic Field of a spring.

Moreover the Gibbs Functions approach gives a very meaningful way of describing the “interaction” of two physical systems simply by adding the Gibbs Functions of the two systems. \[ E = \frac{p^2}{2m} + mgh \] is the Gibbs Function of the two interacting systems Moving Body and Gravitational Field. In the traditional treatment of a body in the gravitational field we speak of the “potential energy”, which is automatically attributed to the body notwithstanding it is the energy stored in the field. The Newtonian view of “Force acting on Body” ignores systematically the “other system”, substituting the outside world with this force. This explains both the efficiency and the limits of the particle model.

This concludes the theoretical settlement which can be considered a simplified version of the general dynamics approach of classical thermodynamics, worded in the frame of the underlying substance model. Which was the base of the success of the computer modeling approach. And now the triangular relation

\[1\] I have in mind an elastic balloon, but don’t ask me to write down the Gibbs Function!
between model, computer modeling and calculus based thermodynamics is complete, because modeling is essentially computer based calculus. The startling conclusion is that currents (derivatives) and physical system defined by their exchanges (increments) and imagined as containers (integrals) are the straight way to teach calculus: mathematics taught with physics experiments! I wish this reversal of the traditional relation between mathematics and physics could please J. W. Gibbs, who wrote of mathematics as a language, but also “One of the principal objects of practical research ... Is to find the point of view from which the subject appears in its greatest simplicity”; and particularly G. Falk [Falk 1990], who held a similar view about physics and mathematics, but first recognized the substance – model educational superiority. And with his pioneering work, together with the research group at the Physics Education Center of the Karlsruhe University, made the powerful conceptual structure of Gibb’s thermodynamics available for teaching at any level from primary school to university. [Herrmann et Al 1985].

Conclusion

I think all this completes the reasons behind the somehow extraordinary role of the energy as “prima inter pares” first primary quantity among equals. Namely the definition of energy as a function of the primary quantities makes of it immediately a new variable itself because of the interchangeability of variables.

But the interesting point is that energy was there from the beginning, disguised as mass. Inertial or gravitational mass? This can lead to another discussion on the improper uses of the word equivalence, but more interesting is that it seems shake the core of my proposal. The discovery – invention of the physical quantity mass as organizing concept of all the observations about weight, although archaic, was a legitimate one. As well as the later discovery – invention of mass as capacity of containing momentum. And the one I tried to outline here, and the last (for now) finding mentioned above, do they indicate a lack of coherence in “The Logic of Scientific Discovery”? This big question is the core of the namesake book by Karl Popper which I understood this simple way: once an objective idea has been invented, all of its theoretical sound consequences will come out, strictly because of its objectivity. Once the idea of whole number has been created, it is only question of time and ingenuity before prime numbers are discovered, and then their distribution investigated...and so on.

So my point is the necessity of rewriting the textbooks not only according to the new discoveries in the field, but also looking for the global coherence of the discipline, and this is a job only teachers can do, because scientists are bound within their contemporary paradigms.

And now a short summary for the disposal of some problems in the teaching of energy.


Here are my suggestions for the revisited teaching of energy. First the retirement with honor from undergraduate teaching of the undifferentiated names and symbols for the exchange energy forms, work $W$ and heat $H$. Moreover freeing the word heat from the physics textbooks cage could have one giant beneficial fallout: we now have a common language word for the abstruse mathematical variable entropy, with no collateral damages and no dumbing down!. It took a big deal of originality to take the view that, what common people expressed with the common word heat, contained almost all of the sound concepts for the metrization of entropy; and it had to come from the chemistry side of science, because there is where entropy becomes an ordinary work tool, losing its mysteries and magic aura. [Job 1976]

To deal efficiently with the exchange energy forms it is necessary to address the energy carrier in a direct or indirect way: hydraulic, pneumatic for energy carried with liquids and gases, “electric energy” for energy carried with electricity, “movement energy” for energy carried with momentum; clearly indicating the primary quantity or the conjugated intensity as in “displacement energy”, “compression energy”, “surface energy” for work, “thermal energy” for energy carried with heat, “chemical energy for energy carried with substances driven by chemical potential.

Second, instead of speaking in abstract of the various form of existence of energy, let’s name the physical

\[ http://en.wikiquote.org/wiki/Josiah_Willard_Gibbs \]

From Gibbs’s letter of acceptance of the Rumford Medal (1881)

Proceedings of The World Conference on Physics Education 2012
systems, so that we know where the energy is. Energy of the fields instead of “potential energy”, so that the powerful Aristotelian word potential could unify all the “potential differences”.

And here we are to third final step, the recover the didactical power of the first law. Having previously recommended to drop all the traditional words used to state it: equivalence, work, heat and internal energy! Because it is time to acknowledge that the modern “form” of the first law is the Gibbs fundamental “form” which not only include effectively all the forms of energy but gives macroscopic physics a general common structure. These results are more than 100 years old, but unfortunately Gibb’s work is yet waiting didactical recognition and employment, only because it had been hidden by the mathematical formalism. I hope to have shown there are also common words for it.

Acknowledgements

The optimism and the hope this article may convey for a future better science teaching is all but mine. I want here to acknowledge the source for it in the monastic dedication to school of Michele D’Anna, whose experiments are the minor part of my obligation; in the protean perseverance for engineering the teaching of science in everyday life of Joel Rosenberg; in the outsize commitment of Fernand Brunschwig and in the enthusiasm of the PTNYC group of teachers.

Corrado Agnes
New York City
November 2012

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4 corrado.agnes@polito.it www.corradoagnes.com/
Dialogic Inquiry on Newton’s Second Law - A Study on Verbal Language as the Most Important Representation Used in the Physics Classroom in Senior High-School

Margareta Enghag, Stockholm University, Department for Mathematics and Science Education
Jan Andersson, Karlstad University, Department for Physics and Electro-technology

Abstract

We report how we ended a research project on a professional development program for physics teachers on dialogic teaching, with a study that compared the discourse in two groups, which were taught differently by the same teacher. The lessons were video-recorded, and episodes were transcribed and analyzed from a socio-constructivist and socio-semiotic perspective, with a framework based on physics representations used. The context was the introduction of Newton’s second law, an area chosen by the teachers themselves, as being especially interesting and difficult to teach. The research question addressed if teachers’ communicative approaches and their staging of experimental and laboratory work during instruction have any impact on quality of the student contribution in the discourse, and on the use of representations appropriated by the students in this context. We conclude that interactive/dialogic talk is dependent on the framing of the experimental work and thought-provoking questions put forward from the teacher, and the opportunity given to the students to discuss for themselves in small groups their interpretation of demo-situations, before discussion in class. To choose examples from students everyday-life make it easier for students to take part in discussions, that later can shift into pure physics reasoning. A reconstruction of experimental work is discussed as an implication for teaching and further research.

References

Introduction

The background for this case study is a research project on a professional development course with focus on dialogic teaching (Alexander, 2008; Mercer, 1995; Mortimer & Scott, 2003; Nystrand, 1997; Wells, 1999). We report how we ended the professional development activities for physics teachers on dialogic teaching, with a case study that compared the discourse in two groups, which were taught differently by the same teacher. The lessons were video-recorded, and episodes were transcribed verbatim and analyzed from a socio-constructivist and socio-semiotic perspective. The context was the introduction of Newton’s second law, an area chosen by the teachers themselves, as being especially interesting and difficult to teach. Newton’s second law gives students in senior high-school a big learning demand (Leach & Scott, 2003), as it is contra intuitive and shows a big step from everyday thinking to the scientific view. The science education researcher (the first author) and five physics teachers and six classes in senior high-schools in a city in Sweden started to ask how Newton’s second law was taught by those teachers involved in the collaboration, and we acted by that like a community of practice (Lave & Wenger, 1991).

In the earlier stage of the project, the five teachers had used video-recordings from their own teaching on Newton’s second law for discussions, and they had taught this topic very differently, with instruction plans ranging from small group work labs, to demonstrations of experimental work. We found big differences in both the teaching and in the student engagement in the different classes.

During the project the teachers wanted to find what influence could be expected from of an increased interactive-dialogic talk during, since they themselves experienced short-comings in both an authoritative demonstrating type of teaching and in too much of discovery learning in the small group work labs used. We decided to go on to using dialogic inquiry on Newton’s second law, as a compromise between the different approaches to teach Newton’s second law we had found earlier. We ended the project by designing this case study to find out how the discourse in the classroom developed if the teacher changed the communicative approach towards more interactive-dialogic discussions. One teacher “offered” to teach one of the classes, which was invited to the university for this intervention to take place. The class was dived into two groups, which were taught differently in the aspect of communicative approaches. The
teacher was challenged to elaborate specific the variables of 1) distribution of talk between teacher and students, and 2) the contextualization of examples given during lessons.

**Theoretical framework**

The importance of the nature of talk in the physics classroom has been studied intensively (e.g. Lemke, 1990; Mortimer & Scott, 2003) based on the ideas from Vygotsky (1934/1986) that language is the mean for coordinating actions and inter-thinking, and from Bakhtin (1981/1986), the importance of distinguishing between primary and secondary discourse. The primary discourse is learnt in the student everyday life, dealing with everyday and practical issues. The secondary discourse is primarily developed at school and provides scientific concepts and ideas. Wells (1999) defines dialogic inquiry as a predisposition for questioning, trying to understand situations collaborating with others with the objective of finding answers (See Wells, 1999, 2001, 2006; Wells & Arauz, 2009).

Physics is found as irrelevant and difficult by many students, and research has given awareness of the importance of the quality in several other aspects than conceptual understanding, to make students feel physics in school personally satisfying (Angell, Guttersrud, Henriksen, & Isnes, 2004; Williams, Stanisstreet, Spall, Boyes & Dickson, 2003). Even if attempts to make science more relevant for student in a scientific literacy aspect (e.g. Ryder, 2001; Roth, 2012; Osborne, 2002; Yore, Hand, Goldman, Hildebrand, Osborne, Treagust, & Wallace, 2004) the problem of making core physics interesting and relevant on a personal plane for students maintain.

At the heart of this paper is the question about focusing on learning of core physics while including a socio-cultural and embodied view. Some researchers have argued, that the difference between cognitive and socio-cultural orientations are incompatible (Sfard, 1998; Säljö, 2000). Hodkinson, Biesta and James (2008), argue against this view, that learning is embodied (referred to Dewey) and that “learning as becoming” (ibid, p.43) expresses that all learning also change the individual’s habitus.

Hodkinson et al (2008, p.30) referring Beckett and Hager (2002) summarize how “learning involves the mental, the emotional, the physical and the practical, and that these are interrelated, not separate”. There is a need to analyze individual learning in the classroom as a process embracing social and contextual structures, the ownership of learning as well as the beginning of getting access to new tools of concepts and models to explore and communicate about objects and ideas of the material world. We see the opportunity for students to share this knowledge, starting taking part in the social and institutional practice around this concept, as an opening for embodied learning that will make them participants in an international community of people who can look at the world of material and ideas with a common language. This empowers students, and changes them, and makes them feel at ease.

Osborne and Collins (2001) analyzed focus group interviews with students, and found that time was a critical factor for disliking physics, and the lack of time for discussion.

The classroom talk is linked to the quality of the learning that takes place and gives opportunity for students to argue and make meaning out of topic discussed (e.g. Enghag, Gustafsson & Jonsson, 2007; Simon, & Richardson, 2009; Mortimer & Scott, 2003; Osborne & Collins, 2001). Also the student ownership, seen as their actions of choice and control, both within small group work and to their individual questions (Enghag & Niedderer, 2008; Milner-Bolotin, 2001) will have impact on their sense of physics as personally relevant.
The teachers’ questions and the framing of experimental work are vital for opening the dialogue in a certain direction (Moll & Milner-Bolotin, 2009; Reeves, Bolt, & Cai, 1999). That experimental work is vital for physics teaching is taken for granted, but how important and in what aspect it influence learning are still under debate. Koponen and Mäntylä (2006) analyze the role of different types of experimental work through history. They conclude that poor outcome is related to the “too straightforward verification use of experiments” in which “the cognitive demand of the laboratory in particular tends to be low” or “the oversimplified inductive use of experiments, as in the so-called ‘discovery learning’ originating in the 1960s, has also proved to be an unsuccessful approach” (ibid 2006, p. 33).

When students are invited to the social plane by the teacher staging physics in the classroom, they internalize physics (Mortimer & Scott, 2003; Wells, 1995) as a disciplinary discourse, and need to be familiar with several of the different physics representations, becoming “fluent” in physics (Airey & Linder, 2009). This process of meaning-making is crucial for students to identify themselves as autonomous, competent physics students that are included in a context that afford relatedness, autonomy and competence, which constitute their self-determination (Ryan & Deci, 2000).

Mortimer and Scott (2003) describe classroom dialogue in two dimensions, interactive/non-interactive and authoritative/dialogic, and by the expression turning-point, they give opportunity to point at the moment when the class are crossing from an everyday view into the scientific view of a phenomena.

- The authoritative interactive communicative approach, when the teacher initiates the conversation by a question, search for an answer, and evaluates this answer. The discourse pattern is typically I-R-E (initiation-response-evaluation), and it is a question-answering pattern that give not much opportunity for the student to discuss further, or give own questions to deepen the discussion.

- The authoritative – non-interactive communicative approach, when the teacher lecture and tell the students about the physics content, using different representations, does not involve the student.

- The dialogic – interactive communicative approach is taken when the teacher open up for student ideas, and give time for discussion. The discourse pattern is typically I-R-P-R-P (initiation-response-prompting-response -prompting).

- The dialogic – non-interactive communicative approach, when the teacher review what ideas students have brought into the discussion, and reason around different views that can be taken. Airey and Linder (2009) analyzed representations relevant for university physics, and divided them into tools, semiotic resources and activities, with categories as Spoken language, Written language, Mathematics, Diagrams, Equipment. Enghag, Forsman, Linder, MacKinnon & Moons (2012) made an attempt to develop the spoken language category with communicative approaches in use. Ng (2011) gave a model for multimodality relevant for information and communication technology, in which the main modes of representations were Written, Verbal, Visual, Embodied and Equipment. We found the mode of representation Embodied of special interest to include in this study, as the instructional design built on teacher experimental demonstrations which much gesturing, and much student reporting orally, i.e. embodied modes of representations.

In this study we draw on the idea that communicative approaches and teacher and student embodied activities in the classroom are part of the representations together with the objects and equipment that describe the context for meaning-making and learning in physics classroom in senior high school. In this sense we define representations as all kind of resources that are in use to bridge all “the ways of knowing physics” (Airey, 2009) between teachers and students and within student small groups.
Research questions

- What kind of interactions between teacher – students take place, and what representations are afforded, when the teacher try to give the student more space to talk?
- What mechanisms challenge students to take part in the classroom dialogue in the two groups, where one group is taught with the intention to use more student-focused dialogue?

Method

Design and procedure

One class was invited to the university and one of the school teachers volunteered to teach two halves of the class with different instructional approaches. The division in two groups was made by their class-teacher, to become equally mixed in abilities. A lesson structure based on series of lab work exercises introduced by the teacher and discussed in groups with a second discussion in class after each demonstration was planned for. The 90 minutes lessons were video-recorded and transcribed verbatim in the parts that included whole class discussions, excluded parts with pure problem-solving which is not yet evaluated. Two additional teachers from the project attended the lessons. The two lessons in the groups were performed the same day. The first lesson aimed to involve students more directly with an authoritative but interactive style, which was the teacher’s ordinary approach, and the second to be more inviting towards a dialogic interactive approach, by giving small groups questions to discuss and then discuss together with the teacher in front of class. Both lessons used a sequence of short experimental demonstrations, to proceed towards better understanding of Newton’s second law. For ethical reasons both lessons were given in the best way available.

Participants

The 23 students of age 18 years, were taking a physics course, mandatory in the Swedish gymnasium (senior high-school), but followed a program preparing for nautical engineering or pilots.

The lesson designs

In both lessons the teacher presented a series of minor demonstrations, and asked the students to comment on each demonstration. The students themselves investigated qualitatively forces on a ballon hovercraft, discussed in class the forces on a wagon with and without friction, discussed air-resistance when a book and a paper was dropped simultaneously to the floor and had time for a problem-solving task to give an algebraic evidence for how acceleration is related to the angel of a declined plane (and to answer the question if mass is involved in the modeling) See Table 3.

Teaching the Lesson 1 Group 1

In the first lesson, the teacher gave introductory demonstrations, which provided situations to discuss motion and forces, see Table 1.

Table 1. The series of demos used by the teacher in Lesson 1.

<table>
<thead>
<tr>
<th>The teacher shows experiments which are discussed in class directly.</th>
<th>Description of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackboard duster</td>
<td>The teacher pushes an eraser across the table</td>
</tr>
<tr>
<td>Wagon</td>
<td>The teacher asks about a wagon moving on the table</td>
</tr>
<tr>
<td>Wagon without friction</td>
<td>The teachers asks about friction in relation to the wagon</td>
</tr>
</tbody>
</table>
Teaching the Lesson 2 Group 2

In the second lesson, the teacher changed the examples to discuss, by introducing five contextualized situations that was drawn on the white-board, and acted on with gestures, for example in the demo about the goal-keeper. The equipment used for the five latter laboratory works was identical, but started differently in the timeline of the lessons, see Table 3.

The teacher shows experiments which are discussed in class directly.

<table>
<thead>
<tr>
<th>Description of activity</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher draws a picture on the white-board.</td>
<td>A Rolls Roys car is standing in the street on a hill without hand brakes in.</td>
</tr>
<tr>
<td>The teacher draws a picture on the white-board.</td>
<td>A parashute jump</td>
</tr>
<tr>
<td>The teacher draws a picture on the white-board.</td>
<td>Going by a sledge in snow</td>
</tr>
<tr>
<td>The teacher drops a stone.</td>
<td>A stone falling down to the floor</td>
</tr>
<tr>
<td>The teacher acts as a player with gestures, and also writes on the white-board.</td>
<td>The goal-keeper</td>
</tr>
</tbody>
</table>

Table 3. The laboratory work activities used in both lessons.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group experiment–balloon hovercraft</td>
<td>A group experiment with balloon hovercraft is set up how the movement are related to forces on the ballon. Students work in groops with one ballon for each group.</td>
</tr>
<tr>
<td>Two wagons with different masses</td>
<td>The teacher releases two trailers with different masses down an inclined plane. A student helps.</td>
</tr>
<tr>
<td>Forces on the wagons moving down an inclined plane</td>
<td>The question of how the acceleration depends on the angle between the inclined plane and the table are discussed in the group after the teacher designed the situation on the whiteboard. The experiments are executed with help from students.</td>
</tr>
<tr>
<td>Falling objects –book</td>
<td>The question of air-resistance is introduced by a falling book with a paper on top in two modes (smooth and scrunched), the teachers demo.</td>
</tr>
<tr>
<td>Coupled wagons are accelerated on a horizontal track</td>
<td>A group experiment t is set up to study how the acceleration are related to forces on the two wagons coupled together</td>
</tr>
</tbody>
</table>

Data-collection

The video-recordings were taken by two cameras, one following the teacher and the front of the classroom, and the other following the class. The video-recordings from the lesson were categorized in episodes, which were transcribed verbatim.

Ethical considerations

The students and the teachers were informed about the Swedish Research Council recommendations regarding classroom studies in schools, and the students and teachers gave their written permission to take part in the study and to share transcripts and use of video-recordings in research and educational contexts.
Method of analysis

To be able to confirm the increased dialogue intended in the second lesson, a simple calculation of words and utterance was accomplished (see Table 5 and Table 6).

To be able to answer the first research question, interactions and representations were identified and coded in the transcripts, and a comparison between similarities and differences in the two lessons were looked for. The modeling and coding-scheme of the interactions and representations found in the lesson are given in Table 4.

Table 4. Coding of representations

<table>
<thead>
<tr>
<th>Episode</th>
<th>The teacher’s use of representations TR</th>
<th>Students’ use of representations SR</th>
<th>Communicative approaches CA, Discursive talk-types DT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Implementation of experiments, demonstrations, body language gestures. Questions, explanations, analogies, comparisons.</td>
<td>Implementation of the experiment, body language gestures. Questions, short answers, explanations, analogies, comparisons</td>
<td>CA-Question&amp;Answers CA-lecturing CA-dialogic CA-reviewing DT- Exploratory Dispositional or Cumulative talk</td>
</tr>
</tbody>
</table>

A model of representations which included communication and communicative approaches was developed based on theoretical studies in the literature, see Table 5. The episodes were coded into teacher and student activities the teachers and what communicative approaches and discursive modes that was taken. To be able to answer the second research question, mechanisms was identified from the video-recordings, and the categories of representations collected from the literature, see Table 5, by discussions partly in the community of practice including the teachers, and partly between the authors of this paper.
Table 5. Modes of representations (Adopted from Ng, 2011, p.28, and modified with Mercer, 1995, and Mortimer & Scott, 2003)

<table>
<thead>
<tr>
<th>MODE OF REPRESENTATION</th>
<th>DEMONSTRATED IN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Written</strong></td>
<td>Text on Whiteboard</td>
</tr>
<tr>
<td></td>
<td>Worksheets;</td>
</tr>
<tr>
<td></td>
<td>Assignments; projects</td>
</tr>
<tr>
<td></td>
<td>Communicative approach in class</td>
</tr>
<tr>
<td></td>
<td>IA-Q&amp;A</td>
</tr>
<tr>
<td></td>
<td>NIA-lecturing</td>
</tr>
<tr>
<td></td>
<td>ID-dialogical</td>
</tr>
<tr>
<td></td>
<td>NIA-reviewing</td>
</tr>
<tr>
<td><strong>Verbal</strong></td>
<td>Dispositional talk</td>
</tr>
<tr>
<td></td>
<td>Group discussions</td>
</tr>
<tr>
<td></td>
<td>Cumulative talk</td>
</tr>
<tr>
<td></td>
<td>Exploratory talk</td>
</tr>
<tr>
<td></td>
<td>Drawings/diagrams</td>
</tr>
<tr>
<td></td>
<td>Tables and graphs</td>
</tr>
<tr>
<td><strong>Visual</strong></td>
<td>Animations/simulations</td>
</tr>
<tr>
<td></td>
<td>Presentations</td>
</tr>
<tr>
<td></td>
<td>Gestures</td>
</tr>
<tr>
<td><strong>Embodied</strong></td>
<td>Experimental work and reporting orally</td>
</tr>
<tr>
<td></td>
<td>Modelling (hands-on)</td>
</tr>
<tr>
<td><strong>Equipment in use</strong></td>
<td>Lab work and demos</td>
</tr>
</tbody>
</table>

Data and findings

Student evaluations judged the first lesson alternative as “good but ordinary teaching – fun with all experiment and demos”, and the second as “very good and interesting with the small group discussions, and to be able to follow if the own ideas gave strong enough arguments in the class discussions”. By including the student voices, we start to report on why this second lesson became special.

The quantity of student and teacher talk

The words and whole sentences as statements were calculated, and showed that the students really were given more talk-space in the second lesson. The students’ number of words was doubled in the second lesson, and their number of statements as well as the length of the statements increased significantly as can be seen in Table 5. The teacher’s talk (see Table 6) was correlated in the same way, the teacher talked with 8 times as many words in the first lesson compared to what the students did (1263/155 = 8.1), but only 3 times more (980/354=2.8) in the second lesson. The teachers talk decreased with 980/1263= 0.78 => 22%. This simple test shows that students talked more during the second lesson then in the first one.
Table 5. A comparison of Student talk in the two groups (i.e. lessons).

<table>
<thead>
<tr>
<th>Students talk*</th>
<th>Number of words</th>
<th>Number of statements</th>
<th>Average number of words/statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>First group</td>
<td>155</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>Second group</td>
<td>354</td>
<td>32</td>
<td>11</td>
</tr>
</tbody>
</table>

*during first 20 minutes of the lesson

Table 6. A comparison of Teacher talk in the two groups (i.e. lessons).

<table>
<thead>
<tr>
<th>Teacher talk*</th>
<th>Number of words</th>
<th>Number of statements</th>
<th>Average number of words/statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>First group</td>
<td>1263</td>
<td>52</td>
<td>24</td>
</tr>
<tr>
<td>Second group</td>
<td>980</td>
<td>46</td>
<td>21</td>
</tr>
</tbody>
</table>

*during first 20 minutes of the lesson

Comparison of communicative approaches used, and resources afforded to the students

We compare the two lesson introductions with codes developed in Table 2. The teacher shows already in the introduction different choice of communicative approach and interaction with the students. In the first lesson, the teacher starts to talk about the formula written on the white-board, and the concepts included into the formula, force, acceleration and mass. He directly asks about the units for these concepts.

Lesson 1: Episode 1 Introduction

Teacher: Yes, Good morning, and welcome! What we together are supposed to do today, is to make this ‘force-equation \( F = ma \) believable. (Point at the text \( F = ma \) on the white-board). And \( F \) is in this case the resulting force acting on an object. The keyword is net force or resultant, and it is not so easy to find out the net force. And \( m \) that’s the mass and \( a \) is the acceleration.

The communicative approach is non-interactive-authoritative, which means that the teacher is lecturing, and at the same time writing and pointing at the white-board. The students are passive and listening.

Teacher: We will not use any units in this context. We do this later eventually. But I can only ask a simple question: What, we usually specify the mass in the SI unit. What is the unit of mass? Student L?

Student L: kilograms

Teacher: For force, then? Student T?

Student T: Newton

Teacher: Yes, exactly…and then we can figure out this one (points at \( a \) in the formula) when we use them later on, we will see when we retrieve it later.

Now the teacher changes approach to be interactive-authoritative, with the characteristic question- and – short -answer dialogue called I-R-E (initiation-response-evaluation). The students can answer shortly to the teacher’s question, but they only fit in the missing words the teacher wants them to find. Most of the students only listen to the conversation without taking part.
Lesson 2: Episode 1 Introduction

If we make a comparison to how the second lesson is introduced, the teacher in this lesson meets the students with a much more inviting description of how the schedule for the afternoon will be, before he directly starts with the first of a series of experimental or thought situations/demonstrations. He refers at first to the students driving licenses, a hot topic for the students who are in the ages when you go for a driving license in Sweden. He creates a positive mode for communication.

Teacher: Welcome to an exciting afternoon as we start, maybe it will be a little different. I will describe some situations, one by one, then you get a minute for you to think about what it is for something, how would you answer the question. So we’ll see ....Everyone has a driver’s license, isn’t it so ... (mumble about this)

The teacher’s approach is inviting, and even if he do not put any questions to the group he include them by talking about their driving-license, which he supposes they have (but only a few have yet). The students listen interested for what will come.

Teacher: There I have parked my Roll Royce! (Draws on the white-board a car on a hill, see Figure 1).

Teacher: I forgot to put the handbrake, and I have no gear in. I get out. What is happening? You describe this to me. Do I get out from a moving car? Now you may discuss some minutes in the groups! (discussion in full swing directly)

Student A: It depends on how steep the hill is ...

Teacher: Has a minute gone now? We ask Nils’ group ... What have you been up to?

The teacher starts directly with the first demo-example, a thought situation the teacher draw as a picture on the white-board. The students are asked, in an interactive –dialogic communicative approach, for their ideas on the situation when the teacher gets out of the car – will it move eventually? He introduces by this small group-talk, but one student answers directly, which is ignored. The groups themselves get a minute to discuss, before one group- member is supposed to report their discussion in class. The students have now opportunity to make impact on how the lesson proceeds. The student representation is group-talk. The teacher’s representation is writing on the white-board and putting driving questions.

In the second lesson the teaching strategy build on small-group discussions on the teacher’s demonstrations, and the questions to open up this discussion become important as well as the contextualization in the demo, that seems to give students enthusiasm for the task. The students directly choose physics concepts to express their ideas in, confirming that these students are familiar with the physics discourse based on physics conceptualization. After the group-discussions, one representative for each group is prepared to give a resume on the discussion.

Lesson 2: Episode 2 First group-discussion report on demo-example 1 The Rolls-Royce

Figure 1. A drawing on the white-board – the Rolls Royce without hand-brakes on parked down-hill.

Student N: “Group N” has concluded that it is very much at play here, including friction, it may well depend on how wide tires it has, what kind of asphalt, how smooth it is, but the car will probably scroll down only if the slope is steep enough. Gravity pulls the car down.

Teacher: I see. Anyone who wants to stock up on something here?

Student B: It accelerates downwards.

Teacher: Yes
Student C: It’s a constant acceleration.

Student D: No. It must be constant steep slope. Teacher: I see.

Student D: No, the air resistance increases as the square well.

Teacher: Yes. Okey. There, I think we’ve got it pretty good. Yea right. Which are the physics concepts here? If I can move to this question then: What are the physics, if you would use this: “scroll down”, “gravity”, “friction”, “acceleration”. If you want to describe the motion accurately with those terms, what will you say?

The teacher first invites the students to give their view by using an interactive/dialogic approach, when he asks one representative for the group to report from the small-group discussion. After the first report the other students are given opportunity to add their ideas and to complete the reporting.

Each of the teacher lead demos promotes interesting discussions with the same pattern as the introductory ones. One thought example/demo of special interest in “The goal-keeper” in lesson two, that includes some direct mathematical reasoning, which include the students, and in which the teacher take part in an exploratory talk with the students (Mercer, 1995)

**Lesson 2: Episode 3 The goal-keeper**

![Figure 2. The goal-keeper — acted by the teacher](image)

This thought example from physics concerns soccer/football, and the teacher intends to calculate the force needed to stop the ball by hands. After a short discussion in groups, the teacher asks for ideas, and invites to discussion.

Teacher: Do you know what The greatest show on earth is? ...There is only one - the World Cup of course. Now you can think about what happens when a goalie, it comes a hard shot - and the goalie tries to take the ball. What will happen then? Explain this! He’ll catch a very hard shot...

(Intense discussion directly in groups.)

Student S: Is he going to glue the ball?

A student makes by the question an important impact on how this discussion will continue, by asking for premises he is interested in. The communication becomes interactive-dialogic, and the student representation is questioning, which gives a discursive talk-types that is exploratory. The sign of exploratory talk is the interrupted sentences, when different persons contribute with ideas and input.

Teacher: Yes, he will glue the ball. (The Teacher paces back and forth while the students discuss, he seems eager to know their ideas on this matter) Well, then we’ll see. There will be a ball coming here with a certain mass and velocity, and then the ball will be caught of this...

Student A: Isaksson ....

Student S2: .... but he doesn’t catch it ....

Teacher: He is Ravelli when he was the best. Okey. Then we take someone who starts describing. Take the word, any group, otherwise I delegate it. Yes ....

Here the teacher encourages and promotes the students to continue the dialogic reasoning.

*WCPE 2012, Istanbul, Turkey*
Student K: Yes, we thought that there is something about this how he does it .... it will make difference if he jumps up and takes it with his hands, that gives a force of resistance.

Teacher: Yes, it does for sure. Now, the idea was that he jumps up and take it, and that he follow the ball backwards a distance. (Showing this with gestures, see Figure 2) If he takes it here (pointing to the knuckle), then it will be something else.

Student K: ... or so here. (Showing another variant to hit the ball away)

Teacher: Yes, I can imagine so too.. Yeah.

The teacher has now coming back on track towards the situation when the goalkeeper really takes the ball with his hand. Student S directly expresses the consequences of this.

Now the teacher and two students have cumulative talk that is still interactive-dialogic.

Student S: He likes some contact time with the ball for sure, so he follows ....

Teacher: Yes, what you’re after is.... well that if he takes the ball here, then he should go with the ball backwards. And what will we then find here? What’s happening with the ball if he does so?

Student A: The sooner he takes the ball, the sooner he influences the force to take the ball.

Teacher: Yes, and what happens to the ball’s speed?

Student S: It decreases. He slows down the ball.

Teacher: Yes. If you take it from an energy point then? What happens to the energy of the ball?

Student A: Well, It goes over into his body in some way.

Here Student A makes a conclusion (not the teacher) that ends this contextual part, and gives the teacher opportunity to turn into pure physics reasoning. In this excerpt the teacher also shows how by just ignoring a “wrong” answer, this becomes accepted as a part in this exploratory event to find out the physics behind the situations. They all suggest part of how to go on.

Teacher: What is the energy from the beginning?

Student S: speed times the weight of the ball?

Teacher: Kinetic energy, \(\frac{mv^2}{2}\). All that energy turns into - what ?

Student A: Heat energy?

Teacher: Force \(F\) times Distance \(l\), right, some sort of mean force. The force he slows the ball down with is a medium force.

Student N: So when he slows down the ball, he gets the energy himself, so he gets speed ....

Teacher: He remains on the ground as he captures the ball like this...

Student S: xxx (inaudible)

Teacher: If we solve this equation with the force he has to use - you can do this (solving equations (authors comment)), can’t you; it becomes

\[
m \frac{v^2}{2} = F \cdot l \implies
\]

\[
F = m \frac{v^2}{2l} \implies F = 900 \text{ N}
\]
His movement is included into his retardation-work going on.

900N, how much mass is he supposed to lift then?

The teacher shows how you can use physics modeling to get a calculation of the force needed to stop the ball. As he also asks for the mass to compare, the students can themselves draw the conclusion again – the goalkeepers box the balls instead of try to glue them, which is far too heavy.

Student S: 90 kg.

Teacher: Yes, then we see - what does a good goalkeeper? They’ve got coaches who can physics!

Student A: They just box it.

Teacher: They just box the ball away like this. (Shows with gestures.) So now you know why they do not glue the ball.

**Conclusions and discussion**

The teacher found a technique to open up the for interactive- dialogic talk, by asking students to discuss demonstrations and hypothetical situations, given by drawings on the white-board, in small-groups, and then ask one representative for each group to summarize what the group had concluded. The students talked more, and used longer sentences in their utterances in the second group as intended. The role of the teacher changed by this towards more of a facilitator and by affording a dialectical exercise this teaching had a flavor of Sokrates’ dialogues.

Similarities and differences in the two lessons were searched for. The role the teacher took in the second lesson introductory part with demonstrations, had some important impact on the dialogue. We found the teacher taking part in exploratory talk with the students. Exploratory talk has been described to go on between students (Barnes & Todds, 1995; Mercer, 1995), but also that the conversation change towards the “final draft”-kinds when the teacher entered into the conversation. Here we saw the exploratory part continue, an acceptance of the teacher as a partner in the on-going meaning making. The teacher’s authority was not jeopardized by this, it was more a sign of trust that this search for expressing the ideas correctly was valuable and important.

We conclude that teachers’ possibility to use interactive/dialogic talk is dependent on the opportunity given to the students to discuss for themselves in small groups their interpretation of experiment-situations, before discussion in class. A reconstruction of experimental work could be to use much more of short demos, and short laboratory problems with equipment used in the small-groups – but still with the teacher waiting for each groups’ comments. We find it likely that this way to give student ownership to more representations enhance their ability to reach more talk-space, more high-qualitative communication and by that to reach “fluency” in physics.

When the teacher changes the style of questioning, this gives new chances for the students to take initiative in expressing their ideas about the demonstration at stake. The representations the students need for this, is the affordances of verbal language. This means also that the students get time to express themselves, and time to discuss. In comparison with the first lesson, the second group expresses the physics instead of the teacher doing so. This is one mechanism that we search for in the second research question – an invitation given to the students to take lesson time to express their ideas about a specific contextual situation in physical terms —that challenge them to take part in the classroom dialogue. Another mechanism we suggest is the contextualization of the physics example in concrete and everyday-life objects that makes it easy to talk about the physics involved – for example to talk about a car staring to move downhill if the hand-brakes are off, or why a goal-keeper never take the ball in soccer, but instead the goalkeeper punches the ball away – examples that challenge them to take part in the classroom dialogue.

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Influence of Different Learning Activities on Knowledge Transfer in Explanatory Model Construction

Mihael Gojkošek, Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
Gorazd Planinšič, Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
Josip Sliško, Facultad de Ciencias Fisico Matematicas, Benemerita Universidad Autonoma de Puebla, Mexico

Abstract

We present results from the study of high-school students’ ability to transfer knowledge in the construction of explanatory models. 196 students were involved in three different learning activities with 3-sided rectangular prism and a ray-box laser. In traditional group teacher showed a sequence of three demonstrational experiments but students were not actively involved. In prediction group teacher asked students for prediction before showing the outcome of the third experiment. In lab group students performed three experiments by themselves in hands-on laboratory activity. Approximately a week after instruction, students were tested with Foil test that is based on the prism foil problem. Students observed two demonstrational experiments with unknown foil, after which they had to construct explanatory models for experimental outcomes. These models should take into account foil’s invisible structure. To assess students’ cognitive abilities, Lawson’s Classroom Test of Scientific Reasoning was used. Our results suggest that little knowledge transfer from learning activities to foil test occurred. Among three tested learning methods, the one asking for prediction seems to improve transfer of knowledge the most. Laboratory activity resulted in less successful transfer, while no transfer was observed in traditional group. In discussion part, we suggest some possible reasons for observed results and consider the importance of correct scientific explanation during the learning process. Time spent on activity had little or no effect on knowledge transfer.

Introduction

According to constructivist view on the nature of knowledge, the process of building new knowledge starts with a foundation of everything that is already known by the learner (Michael & Modell, 2003). Prior knowledge and student’s ability to transfer that knowledge into new situation therefore play an important role in the process of learning. Knowledge transfer is usually seen as the ability to apply knowledge and skills to new contexts and problems that differ from the initial learning situation (Eraut, 2004; Barnett & Ceci, 2002). Considering the similarity between learning activity and the task in which one should apply knowledge, transfer can be near or far (Marini & Genereux, 2004). Additionally, some knowledge and skills, when acquired, are content-specific while other knowledge and skills may be more readily transferred to a new domain (Michael and Modell, 2003). One of important elements involved in knowledge transfer is instructional context, which includes also instruction and support provided by the teacher (Marini & Genereux, 2004). The aim of this study was to compare three instructional practices and their influence on successfulness of knowledge transfer in the case of prism foil problem.

In recent decades several effective teaching and learning strategies were introduced for improving outcomes of science and physics courses (Meltzer & Thornton, 2012). One of the first researchers who emphasized importance of students’ active participation in the learning process was Robert Karplus, who developed instructional model of guided discovery. Three phases of Karplus’s cycle for science teaching are: Exploration, Concept introduction, and Concept application (Karplus, 1977). Newer approach based on work of Karplus, which extended learning cycle by two phases, is so-called 5E cycle. It consists of five phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Bybee et al., 2006). In physics education research, White and Gunstone (1992) presented activities based on three-phase cycle known as Predict, Observe, Explain. Two learning cycles were presented by Lillian McDermott in order to help physics students to overcome resistant difficulties. First cycle consists of phases called Observe, Recognize, Apply, while the second one also consists of three phases named Elicit, Confront, Resolve (McDermott,
These two cycles are not distinct strategies, but are part of much broader learning approach, *Physics by Inquiry* (McDermott, 1996). Active learning educational framework that overcame boundaries of basic learning cycles, and includes a number of strategies how to involve students in authentic scientific tasks, is *Investigative Science Learning Environment* (Etkina & Heuvelen, 2001). Several researches showed that understanding is improved by students’ engagement in the learning activity. Crouch, Fagen, Callan and Mazur (2004), for example, found that learning can be enhanced by asking students to predict the demonstration outcome before seeing it but after showing the introductory experiment. In present study we tried to upgrade this finding by addressing students’ ability to construct explanatory models.

Explanation and its nature played a central role in the history of science. For long time studies in philosophy, anthropology and sociology were focused on how scientists generate and evaluate scientific explanations (Duschl, Schweingruber & Shouse, 2007). Since science education is inspired by the authentic scientific work, several researchers investigated students ability to construct explanations for physics phenomena (e.g. Redfors & Ryder, 2001; Ruiz-Primo, Li, Tsai & Schneider 2010). However, few studies directly addressed a possible connection between this ability and the nature of prior instruction about the phenomenon.

Our research question was: How do different learning activities influence the transfer of knowledge in construction of explanatory models for prism foil?

We decided to compare three kinds of instruction: teacher’s explanation without students’ engagement, teacher’s explanation with asking for one prediction and independent laboratory activity. Students’ ability to construct explanatory models for prism foil was already investigated (Gojkošek, Planinšič & Sliško, 2012), but, without any prior learning activity, problem seemed to be too demanding for high-school students. We hypothesized that learning activity about the optical properties of rectangular prism will increase the number of correct explanatory models.

**Prism foil**

Prism foil is a thin transparent film that is flat on one side and has microscopic prismatic ridges on the other side. Its cross-section can be seen in figure 1. Prism foil is a part of a backlight system in common LCD monitors and can be obtained by dismounting a broken monitor. Its advantage is that one can perform similar experiments as with macroscopic prism without revealing its structure. More information about optical properties of prism foil and its pedagogical applications can be found in the article of Planinšič and Gojkošek (2011).

For the purpose of the research we used two simple demonstrational experiments involving prism foil. When the light beam from a torch is incident perpendicularly to the prism side of the foil, the beam undergoes two refractions and emerges at angles ±α, depending on which side of the prism the beam strikes (figure 2a). When light is incident perpendicularly to the flat side of the foil, it undergoes double total internal reflection and returns back into the original direction (figure 2b). The sequence of these two experiments, after which students are encouraged to explain the structure of the foil on the basis of observed results, is called *prism foil problem*.

![Figure 1. Cross-section of prism foil observed under the laboratory microscope.](image)
Method

196 students aged between 17 and 19 from three Slovenian high-schools were included in our research. 113 of them were females and 80 were males. Gender was determined from students’ names written on their tests. All three schools were located in urban districts. Physics was a compulsory subject and lessons followed prescribed curriculum. Before they were tested, students took lessons on reflection, refraction, total internal reflection, image formation, diffraction and interference of light. Our study was implemented in three steps: first students were involved in the learning activity with prism that was followed by two tests – Foil test and Lawson’s Classroom Test of Scientific Reasoning.

Learning activities

Students were involved in three kinds of learning activities with a laser ray-box and a 3-sided prism made of Plexiglas with isosceles rectangular triangle as a base surface. Three test groups, called »traditional«, »prediction« and »lab« group, were formed for the purpose of the research.

In traditional group physics teacher showed students three demonstration experiments. First experiment showed double refraction of the laser beam that occurs when light is incident at the angle of 45 degrees to the prism (see figure 3a). Second experiment was total internal reflection of the beam when light was incident perpendicularly to one of prism’s shorter sides (see figure 3b). In the third experiment teacher presented double total internal reflection when light was incident perpendicularly to the prism’s longer side (see figure 3c). Teacher performed the experiments and explained observed results using Snell’s law in a qualitative way with minimum engagement of students. The whole activity took about five minutes.

In the prediction group teacher showed students first and second demonstration experiment (double refraction and single total internal reflection) in the same way as it was described before. Then he showed the set-up of the laser ray-box and the prism for the third experiment and asked students to predict the outcome without showing the experiment. Students draw their predictions in their notebooks. After that the teacher performed the experiment whereupon one of the students was encouraged to explain observed result loud and then the whole class discussed it. Such activity took between 5 and 10 minutes.

Figure 2. a) Light beam incident perpendicularly to the prism side of the foil undergoes double refraction and emerges at angles ±α. b) Light beam incident perpendicularly to the flat side of the foil undergoes double total internal reflection and returns in the original direction.

Figure 3. Sketches of demonstrational experiments performed with rectangular prism and laser ray-box.
In the lab group we divided students into groups of 4 or 5. We gave them written instructions for the laboratory activity that included sketches of the experimental set-ups like those in the figure 4. Their task was to perform each experiment, to draw a ray diagram of observed result and to explain result by using laws of involved optical phenomena. Students wrote their answers in the lab reports. The whole activity took 45 minutes.

![Figure 4](image)

**Figure 4.** Sketches of experimental set-ups for laboratory activity in lab test group.

**Foil test**

Approximately one week after the learning activities took place students were tested with Foil test. This test is based on the prism foil problem and was developed by our research group. We assumed that prism foil is an element unknown to students. Instead of the name “prism foil” we used a term “a special foil” in order not to suggest its structure. Part of the foil test consisted of two demonstrational experiments in which students observed the split of the light beam when light was incident perpendicularly to one side of the foil, and reflection of the beam, when it was incident perpendicularly to the other side.

In the first question we asked students to sketch and describe the observed outcomes of the experiments. In second question students’ task was to draw and to verbally describe their explanatory model for the foil’s structure. Additionally, they had to name an optical phenomenon that might be the reason for the observed results. At the end of the task they were encouraged to express, on the scale from 1 to 5, their confidence in correctness of their explanatory model. In the last question we asked them if they were surprised on the outcomes of the experiments and if they were, what was that surprised them most. It took students approximately 30 minutes to finish the test.

**Lawson’s Classroom Test of Scientific Reasoning**

As a reference test we used Lawson’s Classroom Test of Scientific Reasoning (CTSR). The test was developed by Anton E. Lawson as an instrument for measurement of formal-level reasoning (Lawson 1978). Reliability of the test was confirmed in several studies (e.g. Lawson et al., 2000; Ates & Cataloglu, 2007). Revised version of the test with 24 multiple-choice questions was translated into Slovenian language and used in present study.

Questions were combined in 12 pairs of form question-argumentation. Each pair was coded with one point when both answers were correct and with none otherwise; total number of points was 12. Students who scored between 0 and 4 points were classified as concrete-logical thinkers, students with scores between 5 and 8 were classified as transitional and students with 9 points or more were classified as formal-level thinkers. Reliability analysis gave value for Cronbach’s alpha coefficient 0.724, which is comparable to results reported by other researchers (e.g. She & Lee, 2008).

**Analysis**

In the analysis of the foil test we coded optical element (or physics concept) that was proposed as the basis of foil’s structure by students. Similar to our previous research (Gojkošek, Planinšič & Sliško, 2012) we formed nine groups named after key elements included in the explanation: *prism, lens, diffraction grating, mirror, channel, layer, other, incomplete,* and *no model*.

We also coded quality or sophistication of explanatory models and their consistency with common physics knowledge on a scale from 1 to 5.
Models that give no explanations were coded with 1. Models that just describe the observed result but do not provide any explanation for the foil’s structure or are incomprehensible were coded with 2. In this group were classified also those explanatory models that include only a sketch without verbal description or verbal description without a sketch of the foil. (Note that students were explicitly asked to use both representations in the explanatory model construction task!)

We split code 3 into 3 subcategories. When a student described the structure of the foil, which by his/her opinion was crucial for observed results, but did not connect this structure with specific optical phenomenon, we coded this with a code 3.1. Code 3.2 was assigned when a student explicitly stated some physics (optical) phenomenon that on his/her opinion played a crucial role for the observed outcomes of the experiments, but the structure of the foil, which would employ this phenomenon, was not addressed. Code 3.3 was assigned to explanatory models that consist of optical phenomenon and description of the foil’s structure, but these two did not form a consistent whole (e.g. student states non-existent optical phenomenon or uses optical elements and phenomena contradictorily, like »the lens reflects the light«).

Explanatory models that described the structure of the foil and employed corresponding physical concept in the explanation, but contained one or more physical mistakes, or the use of the concept is inconsistent, were coded with 4. Usually in such models the use of physics concept differed from generally accepted physics knowledge in a way that the outcomes matched observed experimental results. A typical example is diffraction grating that produces interference maxima only in two symmetrical directions (without central reinforcement) or diverging lens that splits parallel beam of light into two separate beams.

Models that included description of the foil’s structure, employing corresponding physical concept in the explanation in a consistent way, and contained no mistakes were coded with 5.

**Data and findings**

Average score measured by the Lawson’s Classroom Test of Scientific Reasoning was 7,6 (63,5%). 30 students (15,3%) were classified as concrete-logical thinkers, 90 students (45,9%) were classified as transitional thinkers and 76 students (38,8%) were classified as formal-logical thinkers. These results are similar to reports of students’ reasoning levels in other studies (e.g. Marušić and Sliško, 2012; Ates and Cataloglu, 2007). Reasoning abilities of students in three test groups were comparable. Average scores of students in traditional, prediction, and lab group on CTSR were 7,3 (61%), 7,6 (64%) and 7,1 (59%), respectively. The percentages of concrete-logical, transitional, and formal-logical thinkers in each group are presented in figure 5. Differences of students’ score on CTSR between test groups have not proven to be statistically significant (ANOVA: F=0,61, p=0,54). However, unpaired t-test showed statistically significant difference between Lawson’s scores of males and females (70% vs. 55%, respectively, t=5,52, p<0,001). No other gender-related analysis has been made.

![Figure 5](image_url)

**Figure 5.** Comparison of students’ cognitive abilities in traditional, prediction and lab group. Percentages of concrete-logical, transitional and formal-logical thinkers in each group are very much alike. The difference between groups showed not to be statistically significant.
Only 5 students out of 196 succeeded to construct entirely correct explanatory model. 4 of them were tested in prediction group and one in lab group. Their average score on CTSR was 82%; four of them were classified as formal-level thinkers while one of them was classified as concrete-level thinker (she scored 33%). There was also one student in lab group who constructed partially correct explanatory model – instead of double total internal reflection he explained reflection of the light beam on one side of the foil through total reflection on its flat surface. Total number of explanatory models that involved prism(s) in some way was 3 in traditional group, 5 in prediction group and 3 in lab group.

No big difference between the frequencies of quality codes for explanatory models in three test groups was found. Mostly students constructed explanatory models that were coded with codes 2, 3 (which includes codes 3.1, 3.2 and 3.3), and 4. Only a few students constructed explanatory models of a highest quality and also only a few constructed no model at all. Percentages of explanatory models of different qualities in traditional, prediction and lab group can be seen in Figure 6. Since the frequency of quality codes in test groups were similar, we combined all results in one group and analyzed them.

Figure 6. The graph shows the frequency of occurrence of explanatory models coded with quality codes 1-5 in traditional, prediction and lab group.

We found a strong connection between the quality of explanatory model and score on Lawson’s CTSR. Almost 60% of concrete-logical thinkers constructed explanatory model that was coded with quality code 2, while this percentage drops to approx. 40% in transitional and less than 15% in formal-reasoning groups. Quality code 3, which includes codes 3.1, 3.2, and 3.3, was assigned to approx. 25% of concrete-level thinkers, while these percentages in transitional and formal-level groups are about 45%. Among quality codes 3, code 3.1 that was assigned to explanatory models based on description of the structure was the most frequent in all reasoning groups. This was followed by code 3.3, while code 3.2 (explanatory models based on optical phenomenon) was assigned less frequently. Additionally, we found that no code 3.2 was assigned in concrete-level group, while it was assigned to approx. 10% of explanatory models in other reasoning groups. We found significant increase of explanatory models of quality 4 – while there is only 10% of such models in concrete-level and 15% in transitional reasoning groups, 35% of such explanatory models constructed by formal-level thinkers can be found. Results are shown in figure 7.

Discussion and Conclusions

Since only 5 students out of 196 (2.6%) were able to construct entirely correct explanatory model, we believe that little transfer of knowledge from learning activity to prism foil problem occurred. Comparing results to our previous research (Gojkošek, Planinšič & Sliško, 2012) we can see that active learning methods may improve transfer of knowledge, but the complexity of the testing problem still results in a strong floor effect. Several possible reasons for such poor achievements can be considered.
First, transfer of knowledge from learning activity to prism foil problem is a far transfer. It seems that both problems do not appear similar to students and probably the most difficult task for them is to transfer knowledge from macroscopic (prism in the learning activity) to microscopic scale (prism foil). Another factor that influences the distance of transfer is the time elapsed between learning activity and testing problem. We believe that students would be more successful if the foil test would be administrated immediately after the learning activity.

Secondly, a question what was learned by students in the learning activities should be explicitly addressed. People must achieve a threshold of initial learning that is sufficient to support knowledge transfer (Bransford et al., 2000). We believe that, at least in the traditional group, this criterion was not satisfied. The length of the learning activity and poor engagement of students might have resulted in little (or no) knowledge, which was not sufficient for successful transfer.

Thirdly, the complexity of the prism foil problem may require that the problem is addressed in several steps. In our previous research (Gojošek, Planinšič & Sliško, 2012) two different task sequences were applied during the problem solving. We showed that students were more successful, when they observed surprising result at the beginning, which was followed by observation of second experiment that provided additional (less or not-surprising) data. Breaking larger problem into smaller sub-problems that are easier to comprehend is an effective strategy in problem solving (Gick, 1986). In present study both experiments were presented at the same time. Consequently, students had to operate with greater quantity of the information, upon which a consistent explanatory model should be built. Especially for concrete-logical thinkers this is a challenging task.

Our results suggest that students in prediction group were the most successful ones (4 entirely correct explanatory models – 5,3%), followed by lab group (1 entirely and 1 partially correct explanatory model – 1,8%), while students in traditional group did not construct any correct explanatory model. Also the number of explanatory models that involves prism in any way suggests that prediction group was the most successful one. Those results provide further support to belief that learning with students’ active engagement in the form of prediction of experimental outcomes provides more knowledge in comparison to traditional methods (Crouch, Fagen, Callan & Mazur, 2004). We believe that students’ participation resulted in deeper knowledge, which was observed through more cases of successful knowledge transfer in the prism foil problem solving.

We hypothesized that hands-on laboratory activity might provide even deeper understanding, which, however, our results does not suggest. One possible explanation for that may be found in the method.
of students’ investigation. They got precise instructions for the laboratory activity and their task was to explain observed results, using knowledge of corresponding physics phenomena. However, at the end of their activity, teacher did not provide them any explanation model, which would support (or disprove) their assumptions and explanatory schemes. Authors believe that the lack of teacher’s explanation may result in less learning, as students’ explanations without a support of authority (teacher) remain just speculations and their understanding of the observed process remains unevaluated and questionable. Our results suggest that lab exploration alone, without any reflection on previous knowledge, may not be enough for a meaningful learning and consequently successful transfer of knowledge. These results are consistent with similar findings related to learning by unassisted discovery (Mayer, 2004).

Another important notice is that time spent on the activity is not the most important factor for the successful transfer. Learning activity in lab group lasted 45 minutes, while in prediction group it took less than 15 minutes. Despite much shorter time spent on the instruction, students from prediction group seem to be more successful in the transfer of knowledge. On the basis of this result, we conclude that more important than duration of the learning activity is its nature. In other words: it is more important how we teach students instead of how long we teach them.

The fact that most of the students who constructed correct explanatory models are formal-level thinkers supports the finding from our previous study: formal reasoning skills are an important factor in construction of explanatory models for prism foil. However, there was one student that managed to find the solution of the problem with concrete-level reasoning skills. This may suggest that asking for predictions during demonstration experiments may help non-formal thinkers to transfer knowledge.

The nature of instruction methods does not seem to influence the quality of students’ explanatory models. This is not a surprising result. Short learning activity may increase knowledge, but has much smaller impact on the development of competences needed for construction of sophisticated and consistent explanatory models. On the other hand, connection between quality of models and students’ cognitive level was expected. Higher cognitive abilities like hypothetico-deductive reasoning are essential in construction of complex explanations based on observation of surprising data.

We believe that frequency of the code 3.2 also indicates differences in students’ reasoning abilities. Note that no concrete-logical thinker constructed the model coded with quality code 3.2. This code was assigned to explanatory models based on knowledge of optical phenomenon involved in the experiment, which, on the other hand, contained no or too few information about the structure of the foil. It would be contradictorily if a concrete-level thinker would base his/her explanation on abstract concepts like those composing the transferable knowledge of optical phenomenon in question. Such models, however, were found in transitional and formal-level reasoning groups.

In our study, we investigated ability of 196 high-school students aged 17-19 to transfer knowledge from learning activity to prism foil problem solving. Three different instructional methods were used: teacher’s demonstration and explanation of observed results without students’ engagement was performed in traditional group. In prediction group teacher showed and explained two experiments, while the third one was performed after students’ prediction of its outcome. In the lab group students were involved in unguided laboratory activity, in which they performed all three experiments by themselves. Students were later tested with Lawson’s Classroom Test of Scientific Reasoning and Foil test.

Our results show that little knowledge transfer from learning activity to prism foil problem occurred. It seems that students in the prediction group benefited the most from the instructional method, while transfer was poorer in the lab group and was not observed in the traditional group. We recognized the distance of transfer, low effect of learning methods and single-step problem solving strategy as possible reasons that little transfer occurred. Additionally, we found that asking for prediction during demonstration experiments may help non-formal thinkers to transfer knowledge. Inquiry based laboratory explorations without explicit reflection on previously acquired knowledge on the other hand may not be enough for successful knowledge transfer.
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School Outreach Program for Teaching Optics: Let’s Start With Holography

F. Favale, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, Como, Italy  
M. Bondani, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, Como, Italy, Istituto di Fotonica e Nanotecnologie – Consiglio Nazionale delle Ricerche, Como, Italy

Abstract

Optics is a great opportunity to face a part of our daily experience and offers subjects suitable for effective demonstrations and for simple but not trivial explanations. Some of the most interesting topics are vision, photography, interference, holography, color. In the framework of the “Piano Lauree Scientifiche”, funded by Italian Ministry of Education with the aim of supporting the teaching of sciences in Secondary Schools, we have developed a conceptual and practical path to teaching the principles of optics that are at the basis of photography and holography. The course starts from vision, passes through photography, interference and diffraction and finally gets to holography. The program we present here is aimed at helping students to deepen their standard optics knowledge or to make more interesting their first approach to optics. During the past years we have involved in the project more than 200 students per year who attended not only scientific and technical curricula but also humanistic ones. The activity is supported by a portable set-up to make holograms with students in their schools that does not need sand-boxes or more complex vibration isolated tables. Depending on the requested degree of deepening into the subject, students have been involved in up to eight hours of theoretical lessons supported by experimental demonstrations and eight hours of hands-on laboratory for the realization of both transmission and reflection holograms.

Keywords: holography, outreach, secondary school, practical work

Introduction

During the past years, since 1995 up to 2006, less and less Italian students have attended the so called “hard” science, mathematics, physics and chemistry, university courses. In addition, especially High School students have shown a lack of interest in studying mathematics and physics. To face this situation, many activities were born to make teaching physics and mathematics more attractive and engrossing. One of the most important actions is the National Project for supporting scientific vocations, the so called Piano Lauree Scientifiche (PLS), promoted by the Science Faculties and funded by the Ministry for Education and University. In many cities and regions, other initiatives were born funded by local organizations or foundations.

In this framework, a conceptual and practical path to teach the principles of optics has been developed by the Department of Science and High Technology at Insubria University in Como, with the aim of supporting the teaching of sciences in High Schools.

Optics is a great opportunity to face a part of our daily experience and offers subjects suitable for effective demonstrations and for simple but not trivial explanations. For example we may think about the atmospheric optics, the blue color of the sky, the color at sunrise and sunset or the rainbow. Some of the most interesting topics are vision, photography, interference, holography and color. Among so many topics, photography and holography are especially referred by the authors. On the one side, photography is an experience that touches students directly, but people often use new digital compact or reflex cameras without any knowledge of the optical principles connected with the camera, such as color, focus, depth of field and have very few skills in composition and photographic techniques. On the other side, holography is a mysterious technique filling everybody with wonder: still in XXI century, few people have seen a hologram or know what it is. For examples most people don’t know that holograms are used for money secure check.

International research points out holography as a successful teaching tool, highly motivating for experimental teaching of optics (Olson, 1992; Abramson, 1991; Pombo, 2001; John, 2000), and several papers can be found in the literature, describing how holography can be used in classroom (Olson, 1992;
Dyomin, Polovtsev, & Olshukov, 2009; Jeong, 2000; Hansen, 1995; Wirth, 1991) and also with children (Jurewicz, 1989). Not only holography can be a topic with a certain “glamour appeal” (Hansen, & Swez, 1995) but the physical concepts and the steps of making a hologram prove to be a powerful tool to understand other topics in optics like interference, diffraction, imaging and thus it becomes also a concrete experience of those concepts in real word (Latham, 1986). Nevertheless, in Italy there is a lack of activity in this field.

Holography seems to be considered a difficult topic only suitable for university courses and requiring too expensive laboratory equipment. So holography is not presented during the normal school activity and it is part of standard programs in very few university courses. Moreover school teachers have very few possibilities to improve their knowledge about this topic also because it is very hard for a school teacher to get through the academic papers.

Here we present a program devised to help teachers and students to make more interesting their first approach to optics or to deepen their standard optics knowledge. The teaching pathway has been proposed to many High School classes involving 16-19 year old students who attended not only scientific and technical curricula but also humanistic ones and some parts, except the developing step, were also performed during public demonstrations with adults and children.

The program

2.1 Rationale

From the questions that emerged during the course, we noted that students, and people in general, find it difficult to think that it is possible to make images without a lens system because their attention is focused on the imaging system and not on the light. When we ask somebody “What are you seeing when you say you see something?” it is difficult to find someone answering “I see the light”. They answer “I see the pen, the bottle...” the objects not the light that enters the eyes! This can create some misconceptions about optical phenomena and image formation. One example can be made to illustrate this situation. Let us make the image of an object by a converging lens on a white board or paper. Then let us ask students to predict what they will see if we partially cover the lens with a black cardboard. Most students will answer they will see half the image on the screen instead of a complete but less defined image.

We think that the effort to explain different imaging systems, such as pinhole cameras and holography, in comparison with more conventional ones can help overcoming such misconceptions.

2.2 General concepts

Depending on target students, some holograms can be shown at the beginning of the course to compare their features with those of photos, or at the end of the course, as practical implementation of presented theoretical concepts. In any case, students are asked to puzzle out some questions that have the aim of pointing out preconceptions and to turn the attention to usually neglected aspects of the phenomena:

What does making an image mean?

What do we mean by saying “I see a hologram” or “This is a photo”?

Where actually is the object that I see in a hologram?

Why is our eyesight a three dimensional imaging system?

Why are photos not three dimensional images?

How can we cheat our brain to see in a three dimensional way?

During the teaching path, other questions will arise concerning what is a wave, what is the phase of a wave, and what have they to do with holography; what is coherent light, why do we need lasers to make a hologram, how many ways do exist to make holograms, and many others.

The project has been proposed during the past years. We have involved in the project about 200 students per year who attended not only scientific and technical curricula but also humanistic ones. This project is particularly devoted to 16-19 years old students but the content can be modified to suit younger students.

WCPE 2012, Istanbul, Turkey
Depending on the requested degree of deepening into the subject, students have been involved either in eight hours of theoretical lessons supported by experimental demonstrations and eight hours of hands-on laboratory or in a smaller plan lasting five hours only.

The course starts from vision, passes through photography, interference and diffraction and finally gets to holography, even if the topics are not strictly separated in a rigid timeline. The course is enriched with demonstrations that, in our purposes, are not used exclusively in a merely academic and demonstrative way or as a “closed” activity where students just follow the “steps” in a protocol, but are a useful tool for building a new knowledge starting from wonder.

At the end of the course, the students will get a quite large overview about the principles of image formation, both from the practical point of view and from the theoretical one.

2.2 Course outline

Starting from the words of D. Gabor, “Holography is a method of photography by coherent light in which a light wave issuing from an object is ‘frozen’ into a photographic emulsion by means of a second beam of coherent light, and afterwards ‘revived’ by the second beam alone”, (Gabor, & Stokes, 1969), students are introduced to the concept of image formation and wave front reconstruction by multimedia presentations and hands-on demonstrations.

The simplest way to reconstruct an image is the pinhole camera, a lensless imaging system. We provide students with hand-made pinhole cameras built-up with “whiskey boxes” and black cardboard. We also use a digital camera with a body cap pinhole connected to a computer to see the images on a screen and to discuss the pin-hole images with the students, in order to pick out their peculiar features and limitations.

After the pinhole camera, students are introduced to the world of photography. We discuss focusing systems, deep of field and make a brief introduction to color and color space. Our attention is strongly focused on some of the tips and tricks for rendering 3D vision in photography. In fact photography is an imaging system that produces images of a real three-dimensional world on a flat medium, thus actually losing one dimension: it is a 2D recording of our 3D experience. In photography we are able to fix only the distribution of field intensity over the photographic medium and we miss the information of the object depth that is carried by the optical phase of the field that cannot be directly recorded.

At this point of the path, we introduce human vision and how human brain can be deceived and forced to build 3D images by stereoscopic vision. We talk about optical illusions: this is a real engrossing topic that can be used as a bridge to holography. In fact, holography is not an illusion and our brain is not deceived while looking at holograms. When we look at a hologram, what our eyes see and our brain elaborates is a light that carries the entire information regarding the object of which we are making the “image”. This is the topic of the last step before the hand-on realization of the holograms: how is it possible that light from a holographic plate can be the exact reconstruction of object light field?

This is actually the crucial point of the path and to explore it we need to introduce the concept of wave and wave phase, the superposition principle, interference and diffraction. In an effort to make this issue more understandable, lessons and demonstrations take advantage of a setup provided with both a Michelson and a Mach-Zehnder interferometers so as to make interference fringes immediately visible to everybody. The use of interferometers during the lesson allows pointing out that phase differences introduced by path differences can be encoded into an intensity modulation. This is actually the basic idea of holography. Making a hologram requires the recording of interference patterns between light from a fixed point source and light from each point on an object.

In the final part of the path, we explore almost all the features of the holograms from recording to reproduction. We also point out that different kind of images can be obtained from a single hologram. It is possible for example to project on a white screen the real image produced lighting a hologram by a cheap laser pointer. As we will discuss later this is not only interesting but also extremely helpful for a better understanding of holography.
As it has been said above, demonstrations and laboratory activities are very important for didactics. For this reason, in our outreach activity in the schools, real holograms are realized together with the students. During the course, students follow all the steps of the registration of both transmission and reflection holograms, including the preparation of chemical solutions for the chemical processing of the photographic plates, which is very similar to photographic one since both processes use silver halide emulsion. The activity is supported by a portable set-up to make holograms with students in their schools. Other portable teaching kits for holography have been presented by other groups: Voslion and Escarguel (Voslion & Escarguel, 2012) created a kit that can be packed into a small case and can be used to illustrate some fundamental principles of holography; “Litiholo,” a division of Liti Holographics, has recently revolutionized student-friendly holography by coming up with a self-developing “Instant Hologram” film, making the production of holograms possible without the use of developing chemicals (Chiaverina, 2010).
These are the main features of our set-up:

It does not require an extreme mechanical stability. Normally this is one of the most strict requirements for holography. Some holograms have been recorded to check the range of tolerable vibrations and in this set-up they do not seem so detrimental.

No spatial filtering. This means that the set-up is easier to align.

Extremely compact. It is mounted on a 60x50x0.5 cm³ aluminum breadboard with threaded holes to fix the optical elements with screws.

Modular: for both Leith-Upatnieks and Denisyuk recording schemes.

Intuitive ray tracing for object lightening and superposition of object and reference fields on the photographic plate.

Relatively low cost set-up. The system in Fig. 2 costs about 4,000 Euro.

To realize a transmission hologram the light beam from a 22 mW green laser passes through an analogical old photo camera used as a shutter (electronic shutters are expensive), hits a mirror and reaches a beam splitter (BS) where it separates into two beams: the so called reference and the object beam. In turn, the object beam is divided by another BS into two beams to better illuminate the object. Object and reference fields meet together on the holographic glass plate where they interfere.

![Scheme of the portable setup for transmission hologram.](image)

It is important to keep the relative light intensity of the two beams under control. In fact to optimize hologram visibility, the reference beam intensity must be was 4 to 6 times higher than the object beam. To obtain this condition the first beam splitter has a splitter ratio 30/70 (T:R) and a variable neutral density filter is put on the reference beam emerging from the beam splitter (see the optical scheme in Fig. 3) and we keep the relative light intensity of the two beam under control by means of a photodiode. It is also necessary to use the variable filter to compensate the different light intensity from different objects. We use holographic plates with fine grain emulsions (VRP-M Slavich). For these plates the average grain size is 35-40 nm, the resolving power is more than 3000 lines/mm and the spectral sensitivity range includes 488 nm, 514 nm, 526 nm, 532 nm. With a 22 mW green TM₀₀ laser, the typical shutter time varies from 4 to 8 seconds, strongly depending on the surface reflectance of the objects. Plates are 102 x 127 mm² size but we halved them to make them suitable for our set up. Vibrations are pointed out by many authors as
a cause for bad holograms. To reduce vibrations we mounted the breadboard on small vibration isolating feet. Actually with our setup we do not worry about vibration so much even if a deeper investigation of vibration effects is needed.

After the hologram is recorded, it has to be developed. Usually we bring with us all the chemical stuff already prepared. Nevertheless it is possible to prepare the chemical solutions before the registration session together with the students, to introduce another interesting and interdisciplinary topic: the recording and developing process of photographic/holographic plates and films.

Figure 4. Beautiful virtual image from a transmission hologram of GeoMag composition.

Once the developed plates are dry, we take a quite lot of time to examine the holograms by observing the different ways in which the complete object images can be reconstructed. We illuminate the plate with a spot of white thermal light, with the light from a nearly monochromatic source and finally with a laser light and we notice the differences. So we have the opportunity to discuss the coherence of the light. In Fig. 4 we show an example of a hologram recorded during a laboratory session.

One of the most surprising ways to see the image is to put the holographic plate in the same position in the portable setup used for registration. When the hologram is illuminated by the reference beam alone, the diffraction pattern recreates the wave fronts of light from the original object. Thus, the students see an image almost indistinguishable from the original object which in the meanwhile was taken away. The virtual image can be very sharp and deep. If a hologram is broken into small pieces one can still see the entire scene through each piece. Depending on the location of the piece, a different perspective is observed. Furthermore, if a laser beam, for example of a laser pointer, is directed backward (relative to the direction of the reference beam) through the hologram, a real image can be projected onto a screen located at the original position of the object. Moving the laser beam around the hologram it can be shown that each spot recreates a distinctly different two dimensional view of the object. All these kind of observations allow the students to better understand some optical characteristics dealing with hologram, like vision of parallax (that is the image changing its appearance if you look at it from a different angle, just as if you were looking at a real 3D object) or the surprising feature for which every part of a hologram contains the image of the whole object, i.e. that each piece of a hologram contains a particular perspective of the image, but it includes the entire object.
Discussion and Conclusion

With the technological development and the large application of laser light in nowadays society, holography has come to show a great potential in several areas, and in particular in science education (Pombo, & Pinto, 2001).

Experimental holography in High School teaching may not only be considered an efficient tool for contextualized teaching of optics but it also makes optics more interesting and “appealing”. As positive outcome of our activity, last year a group of student asked us to continue their “holographic” experience and was involved in a laboratory activity aimed to investigate the importance of vibrations in connection to hologram quality. Then during the Open Day of their school, they had the opportunity to show their work in a public demonstration.

We can summarize benefits and weak points of teaching simple holography within a High School outreach program to teach optics:

Benefits
- Highly motivating
- Extremely wide topics
- Challenging
- Different possible levels of deepening

Weak points
- Photographic plates are expensive
- Need of some skills in optics and photographic developing
- Like in any experimental work, there are some dead times (plate development and drying) that could bore students

Probably teacher without formal and practical optics background are requested of a period of training to be able to sustain the entire path, but the effort is worthwhile because we believe that this program can contribute to a more effective learning of optics and to a better understanding of its relationship with other areas of physics.

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Newton Meets Planck – A Play on the Tortuous Road to Momentum Currents

C. Agnes, Politecnico di Torino, Italy
F. Herrmann, Karlsruhe Institute of Technology, Germany
M. Pohlig, Karlsruhe Institute of Technology, Germany
J. Ercan, Gazi Üniversitesi, Ankara, Turkey
D. Yilmaz, Gazi Üniversitesi, Ankara, Turkey

Abstract

At school we teach mechanics as if in the past 300 years there had been no news. We still use Newton’s language to describe mechanical interactions. When describing the gravitational interaction between the Moon and the Earth, we say—as Newton did— that the Earth exerts a force on the Moon. No reference is made to what happens in between. It is not that Newton was so naive to believe that the space between the Moon and the Earth did not play a fundamental role in the momentum transmission. In his Principia he refused to refer to this “ether” because at his time no measurable properties of it were known. Therefore his official pronouncement: “Hypothesis non fingo”. His private opinion, however was different. In a letter to the savant Richard Bentley, he clearly argued against such a view: “That gravity should be innate inherent and essential to matter so that one body may act upon another at a distance through a vacuum without the mediation of any thing else by and through which their action or force may be conveyed from one to another is to me so great an absurdity that I believe no man who has in philosophical matters any competent faculty of thinking can ever fall into it.” We still today use the old action-at-a-distance description of the gravitational interaction. Such a description is obsolete since the first field theory emerged, i.e. the Faraday-Maxwell theory. In our play we meet Newton personally, first in his studio, later in Heaven. We also see Newton discussing with Planck, and we hear their comments on the actual teaching of mechanics in the class-room. In this way we learn in an enjoyable manner about the adversities and obstacles that caused mechanics to remain in an outdated state till this day. Is there any hope that one day we get rid of the old concept of empty space?

Persons:
Commentator (C): Corrado AGNES
Newton (N): Friedrich HERRMANN
Planck (P): Michael POHLIG
Teacher (T): Jale ERCAN
Student (S): Duygu YILMAZ

Prologue

C: We believe mechanics is traditionally taught in a very inefficient way. What do we want to improve using theater? The teacher’s awareness of this inefficiency. I like to see it as an application to the community of teachers of the pioneering work of Augusto Boal on participated theater. In a sense a classroom is some kind of theater where the actor teaches and the spectators learn. We actors together with you, spectators, we are Spect – Actors of the teaching – learning of mechanics in a classroom.

C: We are in the study of the great master: Sir Isaac Newton, 6 years after the publication of his Principia Mathematica in July 1693. I think he would like to confess something.
Newton in his study

N: (half in soliloquy, half to the audience) Have now, alas! ...

studied the laws of motion and summarized them mathematically and rigorously. Which was not easy, after all, my opus adds up to more than 600 pages. But now it is known and recognized by many people.

To be or not to be, that is the question

Whether ‘tis nobler in the mind to suffer

No,... this is not my question and it never was my question. My question was how the amount of movement or, as I express myself in my beloved Latin, the quantitas motus, or, as I say in English, the quantity of motion, or simply the motion ... where was I? Yes, the question was how the motion gets from one body to another.

C: Today we say momentum.

N: Of course, I didn't devise these ideas all on my own. I was lucky to be able to stand on the shoulders of giants. The quantity had already been brought up by a Frenchman, Descartes – or Cartesius, as I prefer to call him – and also by a Dutchman, Huygens, whose name I unfortunately cannot pronounce properly. But the great discovery was mine, after all: to wit, that the motion of celestial bodies can be explained by the fact that the amount of motion goes from one to the other. And I can describe all that quantitatively, by my law of gravitation. By the way, this Cartesius is a genuine character. Do you know that he claimed that God when creating the world provided it with a certain, well-determined amount of motion, and since then he no longer cares about the world? In the opinion of Cartesius, the motion simply redistributes in the course of time... I can not imagine God being so idle. Now I must confess you something, but under the seal of secrecy: My book reads quite well, perhaps, but it was not easy to fool the reader. Let us consider the Earth and the Moon. The amount of movement of the Moon is changing permanently, and so is that of the Earth. The Moon receives what the Earth loses, and vice versa.

C: Today we call that momentum conservation.

N: So the motion somehow goes from Earth to Moon, or from Moon to Earth. But how can that function? In between nothing seems to happen. In between is the ether, but unfortunately we know almost nothing about this legendary substance. What then could I write? I couldn’t write that the motion passes through the ether as long as I couldn’t demonstrate any change of it as the motion is passing through it. You see: This is the reason why I invented this peculiar language, which makes no reference whatsoever to the ether. Actually an ingenious trick. ((Quotes)) “The Earth exerts a force on the Moon.” These are my words which may somehow sound unintelligible, but there is not a word about the ether. Of course, I could say that the motion, when going from the Earth to the Moon, traverses the ether, but that would be speculation. I couldn’t write it in a book where every statement follows rigorously from a couple of axioms. Hypotheses non fingo! In reality, of course, this is nonsense. Methinks that science will soon be apt to solve this problem. I am a dwarf standing on the shoulders of a giant, but soon on my shoulders another dwarf will be standing who can look a bit further than I do. But again: actions-at-a-distance is nonsense. Incidentally, I am about to send a letter to Richard Bentley. Hark!

“That gravity should be innate inherent and essential to matter so that one body may act upon another at a distance through a vacuum without the mediation of any thing else by and through which their action or force may be conveyed from one to another is to me so great an absurdity that I believe no man, who has in philosophical matters any competent faculty of thinking can ever fall into it.” This is clear enough, is it not?
C: This was the first opportunity for an action-at-a-distance-free description of momentum transports. It was Newton himself who missed it. All due respect to his “Hypotheses non fingo”! But his Principia would not have suffered if he had described momentum transports with another language: Instead of: “The Earth exerts a force on the moon”, perhaps he might have said: “The motion goes from the Earth to the Moon”. Newton deceased in 1726. His rival Leibniz had died 10 years earlier. Bach was still alive. For the next 150 years the great discoveries and the new theories of physics were essentially limited to mechanics. We now jump into the year 1850, and ask the master how he judges the further development of his ideas. As could be expected, we meet him in heaven.

\textit{Newton in heaven in 1850; a bedsheet proves that he is in the other world; he holds an apple in his hands.}

N: Tempus fugit, time flies. Already 125 years in heaven! Sometimes I am rather bored up here. Occasionally I would have liked to chat with one or other of my colleagues, but unfortunately most of them are not here. One might have hoped that Galilei were here, but apparently due to those confounded inquisitors he is still not allowed to enter, although he was truly a God-fearing man. Old Spinoza – who unfortunately didn’t grow very old – also would have been an enjoyable company, but there is no doubt that he is in hell. Descartes is not here either, most probably he is also down below. Sometimes I envy them altogether, because there the intellectual climate is probably more stimulating than it is here.

((Playing around with his apple)) Oh, the apple. But with my discovery it has nothing to do, in spite of that nonsensical story made up by my niece and that other Frenchman, Voltaire. The simple truth is that I just like to eat apples. But, coming back to what I said some 160 years ago, I must admit that my hope has not been fulfilled. They still struggle away with this action-at-a-distance. And the inconceivable aspect of it is, that this does not seem to bother anybody. So they have still not understood the ether, or do they not have “in philosophical matters any competent faculty of thinking”? These were my exact words, if thou wilt remember, long ago. But what’s he doing there? ((Looks into the distance, \textit{i.e. the Earth})) What’s his name? Faraday, oh, a fellow countryman. Honestly, he seems to be quite a lad. Of mathematics he obviously doesn’t understand much. He looks into this new stuff, electricity, as they call it, and claims that between the magnets there is something, something that really exists. Thus, no action-at-a-distance! Brilliant! This will eventually bring the change. The same should also be true for gravitation! There is something between the heavenly bodies; so I was right. What does he say? He calls it “field”? I am agreed, why shouldn’t I be?

C: That was the second opportunity. But it was not seized either. Let us read what Maxwell wrote in his book about Faraday:

“... Faraday, in his mind’s eye, saw lines of force transversing all space where the mathematicians saw centres of force attracting at a distance: Faraday saw a medium where they saw nothing but distance: Faraday sought the seat of the phenomena in real actions going on in the medium, they were satisfied that they had found it in a power of action at a distance impressed on the electric fluids. ...”

The break-through was not for now. Let us again listen to Sir Isaac, now in the year 1908.

\textit{Newton in heaven in 1908}

N: God Almighty! 182 years in heaven, time passes so slowly. Is it due to this time dilation that the young man believes to have discovered? They have had this field concept for more than 50 years but they still explain gravitation as an action-at-a-distance. But who is this? And what’s his name? Planck? It does sound German, not like that of a true Englishman. Unbelievable! I think he got it!

“As the constancy of the energy entails the energy flow, the constancy of momentum necessarily entails the concept of the flow of momentum.” Good Lord, these could be my words! I would have called it mechanical current, since they already have an electric current. But momentum current or momentum flow is all right for me. This will turn the events! But then this awkward title: “Bemerkungen on...” Oh no, I better read it in English: “Remarks on the principle of action and reaction in the general dynamics”! Typically German. I’m afraid nobody will read it!
C: The third opportunity was also missed. Newton had been right: Nobody read Planck’s article. Let us now, in 2012, have one more look at heaven. Newton and Planck seem to get along quite well, Planck’s Latin is not good enough to talk with Newton, but his English is acceptable.

*Newton and Planck in heaven in 2012*

N: Well, young man, what about your momentum currents, are they now accepted?

P: Do not call me a young man, Sir, I have grown 5 years older than you have.

N: Nevertheless I am 216 years older than you are.

P: Regarding the momentum currents, not much progress. They are mentioned in one or the other textbook. Here for instance, the authors are Landau and Lifshitz, do you know them? But on page 278. Nobody reads a book until page 278!

N: By the way, why don’t we ever see that other young man about whom people proclaim a genius just as brilliant as me, that Einstein?

P: Of course he’s not here. In former times he would have gone to hell. But now they say there is a department in heaven for atheists. I suppose, he is there. Unfortunately, they don’t admit us there.

N: Oh, look at that, someone is laboring with mechanics, a school class!

*On the Earth: teacher, student*

They are working on a simple mechanical problem: A vase is standing on a table. Which are the forces that have to be considered? As the dialogue proceeds, the tone raises more and more, the conversation gets more and more desperate.

T: I asked you to draw the forces.

S: Which forces?

T: All the forces.

S: This force, ok?

T: What do you mean by “this force”? I told you, you must always say who exerts a force on whom. That is Newton!

S: Oh no!

T: So what is this force?

S: The force of the vase on the table.

T: Please: The force exerted by the vase on the table.

S: The force exerted by the vase on the table.

T: And? Is that all? You do not believe the table accelerates!

S: No. The Table also exerts a force on the vase.

T: So what? Does that solve our problem?

S: Yes, it does. Now the vase is in equilibrium.

T: But no, this one is a force exerted by the vase, the other is one that is exerted on the vase.

S: I understand. So I must take the force exerted by the Earth on the vase.

T: So what?

S: Together with the force that the Table exerts on the vase I get zero.

T: And?

S: That’s “action equals reaction”.

T: Unfortunately not. Action and reaction always refer to different bodies.

S: Does not matter, but the vase is force-free. So the table does not feel the vase.

T: You do not mean that seriously! Do you believe, that the molecules of the table, do not notice the vase?

S: Actually, after all, yes. Or, eh, no. Yes. No. The molecules at the surface, next to the vase notice the vase.
T: There you go.
S: So the vase exerts a force on the molecules at the surface of the table.
T: That’s true. But these are molecular forces. Here we do not consider such forces. What we discuss are gravitational forces.
S: Ah yes – But the force exerted by the vase on the table, is not a gravitational force.
T: Strictly speaking you are right.
S: So it is a molecular force?
T: Now stop this, this is hairsplitting! A force is a force!
S: Ok, but is “action equals reaction” not valid here?
T: Yes, of course it is, but in order to see we need one more force.
S: Yet another force?
T: Yes, the force that the vase exerts on the earth.
S: How many forces do we have now?
T: Four.
S: Four?
T: Yes four.
S: But the table, – doesn’t it exert a force on the Earth, and the Earth on the table?
T: Of course they do, and also the tabletop on each of the legs of the table and each leg on the table, and the upper half of each leg on the lower half of the same leg and the lower half on the top half ..... 
S: Faints.

Newton and Planck in heaven
N: (disappointed) What do you say now?
P: I once had pronounced an insight that is still cited today by many: “A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.” I see now that I was wrong. Even if the opponents die, the old ideas remain alive.
C: Maybe this idea of action at a distance is so deeply rooted in our minds that it is almost impossible to get rid of it, ..... But wait!
N: Oh my goodness! Planck, look at this: a classroom, they do mechanics without actions-at-a-distance! And young pupils!

Again a classroom (not the same as before)
T: So, what about the momentum in this case?
S: Comes from the Earth, passing through the gravitational field goes into the vase; from the vase into the table and back into the Earth.
T: Does this remind you of something?
S: A closed circuit, like in electricity. Simple!

Again in Heaven
N: Do you know where that is?
P: I don’t. Oh, ... they call it...
N and P (deciphering): ...Karlsruhe ... Physics ... Course.

Curtain
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High School Students Analyzing the Phenomenology of Superconductivity and Constructing Models of the Meissner Effect

Marisa Michelini, Research Unit in Physics Education, University of Udine, Italy
Alberto Stefanel, Research Unit in Physics Education, University of Udine, Italy
Lorenzo Santi, Research Unit in Physics Education, University of Udine, Italy

Abstract

Superconductivity offers many opportunities to explore a relevant phenomenology interesting for students because perceived as a challenge stimulating the construction of models, activating a critical re-analysis of magnetic and electrical properties of materials, bridging science and technology. In the European projects MOSEM1-2, an educational path was developed on superconductivity for high school based on explorative experiments and on-line measurements concerning the Meissner and the pinning effects. Feasibility tests were performed in several Italian high schools with more than 500 students. A research experimentation carried out with 40 selected students, aged 17-19, was focused on the models they develop analyzing the Meissner effect using the field lines representation. Data were collected by the worksheets used by students and by the audio-tape dialogues in the group activities. A qualitative analysis of the students’ answers, sentences, explicit reasoning and drawings was performed. The students learning paths show a progressive construction of models based on the ideal diamagnetic properties of superconductors, in which the concept of field has an important role.

Introduction

Several researches stress the need to renew high school physics curricula including contents of contemporary physics (Aubrecht, 1989; Gil & Solbes, 1993; Hake 2000, Ostermann, Moreira 2004). Although, the main attention is oriented to introduce fundamental topics as quantum mechanics and relativity (Ostermann, Moreira 2000a), an increasing number of papers evidences the importance to consider other aspects as superconductivity. Demonstrative experiments of levitation in didactic laboratories were proposed in different setting (Schneider et al, 1991; Abd-Shukor, Lee 1998, Brown 2000; González-Jorge, Domarco 2004; Zwittlinger, 2006; Schorn et al. 2008; Strehlow, Sullivan 2009). Educational paths on superconductivity and papers for teachers, presenting the progress in technical applications of superconductors (Ostermann, et al. 1998a, Gough 1998, AAVV 2007), can activate the construction of models, a critical re-analysis of the knowledge about magnetic and electrical properties of materials, stimulating links between science and technology, bridging classical and quantum physics (Ostermann, Moreira 2004), opening a reflection on NOS (Tasar 2009). Educational paths implemented in high school with students and with teachers in formation constitute first positive feasibility tests (Ostermann 2000, Ostermann, Moreira 2000b, 2004; Schorn 2008, Tasar 2009).

To overcome the descriptive-qualitative approach usually followed in the quoted works, in the context of the European projects MOSEM1-2 (AAVV 2010, 2011; Kedzierska et al. 2010), an educational path on superconductivity in high school was developed and experimented by the Italian partners of the projects coordinated by Marisa Michelini at University of Udine. From researches, performed in several Italian schools with more than 500 students and 100 teachers, emerged a differentiated spectrum of educational paths integrating superconductivity in the ordinary high school curricula, involving students in the analysis of the phenomenology and focusing on the conceptual understanding of the processes at the base of superconductivity levitation (Corni et al. 2009; Michelini, Viola 2011; Viola 2010).

Here a research carried out with a group of selected students from all Italy is presented, with the purpose to give a contribution on two levels: the exploration patterns of students facing Meissner levitation; the models developed by students analyzing this phenomenon having the field lines representation as conceptual references.
Methodologies of the qualitative research (Bliss et al. 1983; Erickson 1998; Savenye, Robinson 2011), the
taxonomy of causal model of Perkins & Grotzer (2000) and the Types of Models of Windschitl, Thompson
(2004), are at the base of the theoretical framework of the present study, focalizing on the following
research questions:

RQ1) What models are activated in students from the analysis of different aspects of the phenomenology
and how these models evolve?

RQ2) Which aspects of the levitation students suggest to explore to understand the Meissner effect and
what sort of hypothesis they want to verify/falsify? What models are embodied in such cases?

RQ3a) What models are activated in their analysis of the Meissner effect and RQ3b) What are the
conceptual references that students use?

RQ4) Which are the most problematic knots?

The context of the research experimentation

The research experimentation here presented was performed in 6 hours with 40 students, subdivided
in two groups: GR1 consists of N1 = 24 students of grade 12 (aged 17/18) without previous scholastic
formation on electromagnetism; GR2 consists of 16 students of grade 13 (aged 18/19), with a 1-year
scholastic formation on electromagnetism. The students, selected from schools from all Italy and attending
the Summer School held at University of Udine in July 2011, were involved using tutorials in personal and
free explorations of the breakdown of resistivity (2h) and of the Meissner effect (4h), as it will be discuss
in the next paragraph. Before the activity concerning superconductivity, the students were involved in a
module of 6 hours on magnetic phenomena and electromagnetic induction, constructing operatively the
field line representation and the concept of flux.

The step explored by students, the monitoring tools.

The educational path, at the base of the experimentations here documented, implement an IBL approach
(Michelini, Viola 2011) using a set of hands-on/minds-on apparatuses designed with simple materials and
high technology kits (AAVV2010, 2011, Kedzierska E. et al. 2010), YBCO samples, USB probe to explore
resistivity versus temperature of solids (Gervasio, Michelini 2010). In the experimentation here discussed
the students were involved in the following explorative steps:

S0) Measurement of the Breakdown of resistivity of an YBCO disc;

S1) Exploration of the magnetic properties of different objects: interaction of a magnet and different
objects put on the table, to recognize the ferromagnetic ones; interaction between two free and
constrained magnets, interaction of a strong neodimium magnet and paramagnetic and diamagnetic
systems suspended on a wire or on a yoke in order to make evident even very small repulsive/attractive
forces;

S2) Interaction between a little strong magnet (magnet1) and an YBCO disc at room temperature (T.)

S3) Analysis of the situation: a sandwich composed by magnet1/YBCO/ferromagnetic ring at T=T° is
lifted, pulling the magnet

S4) Levitation of the magnet1 posed on the YBCO disc cooled at the temperature of liquid nitrogen (T_{NL})

S5) Analysis of the stability of the levitation

S6) Students design and perform free experiments to explore the phenomenology

S7) Re-analysis of the Meissner Levitation and comparison with other magnetic suspensions

S8) Drawing the field lines for magnet1 and YBCO at T=TNL

S9) Analysis of the situation S3 at T=TNL

S10) Levitation of the magnet1 posed on the YBCO at T° and then cooled at T_{NL}.
S11) Students synthetize the main characteristic of the Meissner effect

These steps where systematically monitored, using five tutorial worksheets (WS0, WS1-4), audio recording of the student dialogues, notes registered by the researchers conducting the interaction with students. The strategy adopted includes the following phases: presentation of a situation-problem, experimental exploration of it, student individual answer to the questions of the related worksheet, discussion in little group on single questions, discussion in large group at the end of each worksheet.

Data was collected prevalently by the two worksheets used during the initial and final phases of the analysis of the Meissner effect levitation: worksheet-0 (fig 1) and worksheet-4 (fig 2). Qualitative data where supported by the audio taped dialogues of the students during the activity.

Worksheet 0. Preliminary exploration of the interaction of a magnet and an YBCO disc

An initial exploration of the interaction of a disc of YBCO (YBa2Cu3O7−x) with a magnet is proposed, first at room temperature T0 and then at liquid nitrogen temperature Tn.

A. For each situation describe the results of the interaction and the conclusion that can be drawn.

<table>
<thead>
<tr>
<th>Situation</th>
<th>Results of the interaction</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. A magnet is moved closer to an YBCO at T=T0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2. An YBCO disk at T=T0 is over a ferromagnetic ring. A magnet is over the YBCO. The magnet is lifted.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3. YBCO at T=TnL and the magnet moved closer over it</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4. YBCO at T = TnL and magnet levitating, shifted slightly from the equilibrium position</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The point A of the worksheet-0 suggests a preliminary analysis of four situations (S2-S5 and fig. 1), asking “outcome of the interaction and relative conclusion”.

Point B on the worksheet-0 requires students to “Design situations and trials to be conducted to explore the phenomenon of levitation, report them on the table with the hypothesis underlying each (What hypothesis do you want verify?)” (S6).

Figure 2 shows the points A-C-F-G, concerning the analysis here documented.
Figure 2. Points A, C, F, G of the worksheet-4, in which students are required to use the field lines to describe the levitation Meissner effect and then summarize the aspects that characterize it.

In the points A and C students are required to draw the field lines in the configuration shown respectively at $T^\ast$ and $T_{NL}$ (S8). The last two points aim at collecting how students characterize the Meissner effect in a specific phenomenology (point F - S9) and in the final summary (point G - S11).

**Data analysis methodology**

A qualitative analysis (Erickson 1998) of the student’s answers, sentences and drawings was performed, for what concern the following points:

A. Worksheet-0-first part – descriptive models or models with interpretative elements, local and partial models, and global type models, bringing together concepts and processes, providing causal connections (Nersessian 1987);

B. Worksheet-0-second part - models developed with descriptive or interpretative elements of a local and partial, or global and, bringing together concepts and processes, provide causal connections;

C. aspects of the phenomenology that students consider relevant to understand the phenomenon of levitation, focus of exploration proposals and whether they are only procedural or seek to verify/falsify hypotheses;

D. Worksheet-4-Points A/C. Representation of the magnetic field outside and inside the superconductor, at $T=T^\ast$ and at $T=T_{NL}$, and type of representation of the $B=0$ condition

E. Way in which the Meissner effect is described at the end of the experimentation, aspects on which students focus on (points F/G worksheet-4).
According to the taxonomy of causal model of Perkins & Grotzer (2000) and the Types of Models of Thompson, Windschitl M (2004), the conceptual constructs of student were classified in the following categories: Developmental models represent the changes over time, or evolution of an object or of phenomena; Classification models depict relationships among different types of objects; Underlying Causality models evoke causal connections without specifying them; Relational Causal models provide single connections of cause-effect, partial and local; Emergent Causality models include chains of causal relations triggered by global visions of phenomena.

The frequencies of the categories emerged were evaluated, performing a χ² test to evidence differences with ages in the distributions.

Data analysis and findings

The experimental analysis of the breakdown of the resistivity

In the initial experimental analysis of the breakdown of the resistivity of a disc of YBCO, the students evidence in their graphs (Fig. 3), only the start/end temperature of the process (13/40), both of these (27/40), also the initial value of the YBCO resistance (20/27). Captions, completing 19/40 graphics, emphasize the “rapidity” of the breakdown or the short range of temperatures in which it occurs. Only in three cases they provide an interpretation, documenting previous readings on the subject (“at low temperatures to explain the phenomenon at microscopic level there is a theory called BCS, according to which the electrons arrange themselves to form pairs, called Cooper pairs, that do not exchange energy with the lattice”)

The analysis of the graph R-T acquired in real time has activated in all students (40/40) developmental models based on the crucial role of the temperature of YBCO sample. In the majority of cases (27/40), it activated also the recognition that the phenomenon analyzed consists in a sudden change of YBCO properties (27/40). The need for an interpretation of the process remains at an implicit level at this stage, a part for the few students having prior knowledge.

The initial exploration of the Meissner effect

Worksheet0: Situation A1) – As for what concerns the magnet moved closer to an YBCO at T=T° and the observation that does not occur any interaction or at least any apparent (38/40), or a slight attraction (2/40), the students’ conclusions have two disjoint categories classification models, focusing on: the possible magnetic properties of YBCO (MA1-29/40) (“it is not ferromagnetic” - 21/29, “has no magnetic properties” - 4/29, “has paramagnetic properties” 2/29), the ontology of YBCO (MB1 10/40 - “is not a magnet” or “a ferromagnet”). The disjunction between ontology of the system and its properties, also confirmed by the analysis of students’ dialogues, shows that for them there is no implication between the two. In one case the idea emerges (MC1): “there is no electric stimulus between the two materials”, well known identification of electric and magnetic phenomena (Borges, Gilbert 1996).
Worksheet-0: Situation A2) – With regard to the situation in which a magnet lifting the sandwich magnet/YBCO/ring at \( T = T^* \), the models categories emerged are summarized in Fig. 4.

**Figure 4.** Model categories, highlighted in the explanations of the point S3

In the categories MA2.1-3, including slightly more than half of the sample (21/40), the Emergent Causality models have two fundamental aspects to account for the phenomenon: an entity crossing the YBCO, the magnetic field (categories MA2.1 -MA2.2), the interaction (category MA2.3); the attractive interaction between magnet-ring.

The Relational Causality model of Category B includes only the first aspect, being implicit the interaction. The finding that an entity must cross the YBCO in order to observe an effective magnet-ring interaction, common to the 23/40 response of the categories MA2 and MB2, was activated by the exploration of the interaction between a magnet and a ferromagnetic object through a paper or a wooden surface of a table (S1), as emerged in the motivations expressed by the students dialogues.

The Underlying Causality models of categories MC2.1 and MC2.2 remain on the phenomenological description of the interaction of attractive type, made explicit in terms of forces only in MC2.1. There is no correlation between the types of responses and the age of the students, or their previous formation level \( \chi^2(6)=6.4, p<0.01 \). In line with the Galili’s research (1995), only in 5 cases the recognition of reciprocity in the magnet-ring interaction and the analysis of the forces acting is still partial.

Worksheet0: Situation: A3) – In the first observation of the phenomenon of levitation of a magnet above an YBCO disc, previously cooled at \( T = \text{TNL} \), five macrotypes of models, can be recognized:

- **MA3.** Emergent Causality models, in which starting from the observation of the phenomenon, the direction of magnet-YBCO interaction at \( T < \text{TNL} \) is recognized (13/40), the YBCO behavior is characterized (4/13, who has used expressions in point A1) or a property is attributed to the YBCO (9/12, who characterized with a property in the YBCO at \( T^* \)), acquiring “diomagnetic properties” or “diamegnetic behavior” (6/13), evidencing unspecified magnetic properties (3/13), showing “ferromagnetic behavior” (1/13), the “properties of a magnet” (3/13).

- **MB3.** Emergent Causality models, in which the magnet levitates because the YBCO generates a magnetic field (4/40)

- **MC3.** Related Causality models based on the force concept (15/40) and in particular, on:
  - equilibrium of two forces (8/40): “There is a strong repulsion, but also attraction between the two bodies”, “There is an equilibrium between the gravitational force and a repulsive force”; the effect of a single force, repulsive (9/40) or attractive (1/40)
  - **MD3.** Related Causality model based on the idea that “The magnet levitates above the steam generated from liquid nitrogen” (2/40).
Two students, finally, simply noted that “magnet is inclined not endorsed on the YBCO” and that “The magnet levitates on YBCO at TNL for the Meissner effect.”

In the category MA3 and in almost all of the answers of the category MB3, on the basis for the choice of the magnetic properties to the YBCO there is an analogical reasoning aimed at giving account only to the repulsion, for those attributes diamagnetic properties to YBCO, only to the intensity of interaction observed, for those assigning to the YBCO or ferromagnetic properties or the property of a magnet.

In the category MC3 we can recognize three different models based on the concept of force: the balance of the Meissner repulsion and attraction due to the residual pinning, the equilibrium between weight and repulsion force, a single interaction force between the magnet and YBCO, which makes account of levitation, in which it is clear the partial analysis of the forces acting already underlined.

The category MD3), definitely in the minority and disappeared in the later stages underlying the knot of recognition that the interaction YBCO-magnet have magnetic nature, emerged in the proposed exploration of other students.

Worksheet-0: A4 – As regards the situation in which the magnet levitate on the YBCO at $T = TNL$ is moved slightly from the equilibrium position, in the table 1 are summarized models of students.

**Table 1.** Model used in the description of the first exploration of the stability of levitation

| MA4 - Behavior | Magnet "keeps the inclined position, the magnet levitating until the YBCO is at $T = TNL$ or falls" | 5 |
| MB4.1 - Equilibrium | Magnet "oscillates, returns to the equilibrium position" | 15 |
| MB4.2 - Equilibrium of forces | "The magnet returns to the equilibrium position, forces are balanced and the magnet remains inclined" | 4 |
| MB4.3 - Equilibrium: Minimum of potential energy | "If the displacement is slight, it back to equilibrium position otherwise if it is greater, it falls out. If the magnet is in levitation, it is in a state of equilibrium and of the lower level of potential energy" | 3 |
| MC4 - Two magnet | The magnet “returns to its equilibrium position. It is realized the case ‘interaction between two magnets’" | 5 |
| MD4 - Diamagnetism | “The magnet back to its equilibrium position. The diamagnetism of YBCO makes the magnet in equilibrium” | 2 |
| ME4 - Magnetic field | “The magnet tends to return to equilibrium. The magnetic field does not allow the leak of the magnet from the field of the YBCO" | 5 |
| MF4 - Electric current | “The magnet remains in the equilibrium position. The YBCO has this behavior below a certain temperature. A current is probably generated, which hinders the movement of the magnet” | 1 |

With the exception of the Developmental models of minority category MA4, in almost the entire sample, the concept of equilibrium is included starting from the description of the phenomenon, resulting the central concept of the Relational Causality models of the category MB4. In the remaining categories, including 13/40 students and Emergent Causality models, the phenomenon is caused by the interaction between two magnets (cat. MC4), the diamagnetism YBCO (cat MD4), the magnetic field created by the presence of YBCO (cat. ME4), the current developed inside the YBCO (cat. MF4). At this stage, the students, with no significant differences between the two groups ($\chi^2(8)=6.5, p<0.001$), analyze levitation mainly as a static interaction between the magnet and YBCO, providing only the dynamic aspects of the last two categories.
When asked to design experiments to understand the phenomenon of levitation, the students proposed on average 2.0±1.1 (max 5) different contexts, and 2.3 ± 1.1 (max 5) actually different experiments.

Next to several proposals for behavior exploration (2/3 “try to see what happens if ...”), a significant part (one third) of the experiments is aimed at verifying/falsifying interpretative hypotheses covering the following full range of contexts (categories not exclusive), all significant for the characterization of the phenomenon: role of T (18/40); properties YBCO (16/40); characteristics of the interaction YBCO-Magnet and in particular its magnetic nature (27/40) ; measurement of the parameters which determine the interaction (26/40); interaction of a YBCO with objects of materials with different magnetic properties (19/40); behavior / electrical properties YBCO (9/40)

Half of the sample adopts a verify approach, proposing to change the geometry or the properties of the systems involved. The remaining half aims at falsifying hypothesis, proposing to explore if the levitation occurs or not by changing a specific condition (e.g. “The magnetic field of the SC is similar to that of a magnet. Observation. If there is a magnetic field, the magnet would turn and would manifest attraction “). There is no dependency between age and approaches (p <0.1). Such an attitude, not common among students (Park et al 2001), is particularly important here as it has led to design situations that highlight the dynamic nature of the processes underlying the phenomenon.

The analysis of the effect Meissner at the end of the path

The representations of the magnetic field at T = T° include lines which radiate from the poles of the magnet, through the superconductor, are open close to the magnetic axe. They differ in the three types shown in Fig. 5, in which emerge the main difference between the groups GR1 and GR2, regarding how they drawn the magnetic field lines: also depicted inside the magnet, which protrude only from the bases of the magnet, frequent drawing, also present in the textbooks (Tipler 1991, Haber-Scaim U, et al. 1995) (4/40 all of GR2); represented only on the outside of the magnet, which protrude from the base areas (28/40, 15 of GR1 and GR2 13); external to the superconductor and protrude from both bases from both side surfaces of the magnet (8/40, all of GR1), as recognized in the exploration of the camp with compasses

**Figure 5.** Representations of the field of the magnet at T=T°
**Worksheet-4 – Point C.** In 38/40 representations of the magnetic field when the superconductor is at $T = T_{NL}$, the following 5 types can be recognized (Fig. 6): MA5) the field lines are present inside the magnet, are deformed in the vicinity of the superconducting winding it externally; MB5) All field lines are external to the magnet and curved upwards; MC5) the field lines are shifted almost rigidly upward and are external to the magnet and the YBCO; MD5) the field lines are produced both by the magnet and by the superconductor; ME5) the field produced by the magnet is external to it and with it rigidly raised, penetrating inside the superconductor. These representations are in agreement with those obtained in previous studies (Viola 2010).

Analyzed in horizontal lines, 33/40 representations of Fig. 6 include the condition $B = 0$ in the SC, peculiar of the Meissner effect. Only for 5 students the magnetic field crosses the YBCO. The same representations analyzed in vertical lines indicate that for 26/40 (categories MA5-MB5-MD5) the interpretative key lies in the deformation of the magnetic field produced by the magnet. The remaining representations (12/40, MC5-ME5 categories) evidence the model for which the magnetic field is only shifted and rises with the magnet, not being changed by the superconductor. When prompted to indicate the cause of the lifting magnet, these students have referred to a “repulsion between …..like magnets, but it is not like that...” The recognition that the interaction is different from that of the interaction between magnets is not followed by the construction of an alternative model.

![Fig 6. Representation of the field at $T = T_{NL}$](image)

**Worksheet4 – Point F. The sandwich magnet/YBCO/disc at $T = T_{NL}$.** Figure 7 shows the types of conclusions about the negative outcome of the attempt to raise the YBCO with a magnet placed above a ferromagnetic ring at $T = T_{NL}$. About one-third have been activated Emergent Causality models centered on the absence of magnetic field inside the superconductor (27/40 of the categories MA6-MB6-MC6). In such models it is also made clear that there is an effective interaction between the magnet and the ferromagnetic ring (9/27) and/or that the process is observed when the YBCO is in a superconducting state (7/27). In the category MD6 the phenomenon is described with Relational models based on the change in the magnetic properties YBCO (“it becomes diamagnetic”). A minority describes the phenomenon with Developmental models (cat MD6) or evades the question (NA).
Figure 7. Frequency distribution of the models embedded in the description of punt S9
Worksheet-4 –Point G. Characterization of the Meissner effect

In the following are reported the categories in which the Meissner effect was synthesized, leading to Fig. 8, the distribution of the related frequencies:

MA7) existence of a critical temperature $T_c$ and/or repulsion/levitation ("The SC below a certain $T$ repels the magnet, thus making it levitate")

MB7) diamagnetism of YBCO, in more than half of cases also $T_c$ ("The Meissner effect provides that an SC, brought below a $T_c$, changes its magnetic properties, becoming a diamagnet presenting therefore the capability to repel the magnets", the field lines "do not cross", "are repulsed outside" the Superconductor, "YBCO screens the magnetic properties")

MC7) $R=0$, in half of cases also $T_c$ ("it is an effect that occurs only below $TC$ and is closely connected to the annulment of the electrical resistance")

MD7) $B=0$ and $R=0$; "The expulsion of the magnetic field related to a fast annulment of the resistance".

The Meissner effect occurring only below a critical temperature is the phenomenological aspect emerged predominantly in the responses of students (23/40), as the only aspect in the category MA7. This effect is characterized indicating that the YBCO becomes a perfect diamagnet or that the magnetic field vanishes inside (21/40 cat MB7 and MD7). A minority characterizes the Meissner effect with the cancellation of the YBCO resistance (11/40 cat MC7-MD7), being a few students who have related electrical and magnetic properties of the superconductor (5/40 cat MD7).

In 15/27 of cases the concept of magnetic field is the basis of the answers from section F to section G.
**Conclusions**

In the perspective of including modern physics in school curricula, superconductivity is a privileged area both for its relevant technological applications and for the different levels of its interpretation. In the context of European projects MOSEM1-2, a teaching proposal was developed on superconductivity integrated into the high school curricula of electromagnetism, focused on the exploration of the phenomenological magnetic and electric properties of superconductors.

Research experimentations have been carried out in several Italian schools and formed the basis for the research documented here, carried out with 40 students of two different age groups (17-18 and 18-19 years old) selected from schools from all Italy.

Activities with students were monitored with tutorial worksheets, making a qualitative analysis of students’ sentences and drawings in the first exploration phase of the Meissner effect and at the end of a 6-hour course. Conceptual constructs of students were classified according to the causal model taxonomy of Perkins & Grotzer (2000) and the Types of Models of Thompson, Windschitl M (2004). These data were integrated with those emerged from the audio recordings of the small and large groups phases.

The main models emerged from students’ responses are centered on the concept of the magnetic field and the magnetic properties of the systems involved (RQ3a), highlighting interesting patterns (RQ1).

In the initial analysis of the levitation of a magnet on a superconductor cooled to $T=TNL$, were identified two main groups of models (RQ1): a first group of Emergent Causality models is based on the magnetic properties or behavior of YBCO in the presence of a magnet, or on the resulting magnetic field created by the presence of YBCO under the magnet; a second group of Relational Causal Models is based on the concepts of force and balance. The static vision underlying these models (RQ1) was modified by some students as early as the preliminary design of the proposed exploration of the phenomenon. These proposals ranged on areas, relevant to characterize the Meissner effect, in which prevail: the analysis of the role of temperature in the process, triggered by the initial experimental exploration of the breakdown of resistivity; the study of how a superconductor interacts with other objects made of different materials, aimed at recognizing its electrical and magnetic properties; the phenomenological parameters of the identified interactions. In more than half of the sample these proposals were intended to falsify and not to verify hypotheses, what is so unusual (Park et al 2001) and rich in implications for the learning process (RQ2).

In the analysis of the levitation magnet on the YBCO, at the end of the path exploration, the majority (5/6) represented the condition $B=0$ inside the superconductor with three different models: the resulting

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field that surrounds the YBCO; the upward deformation of the field lines produced by the magnet; the translation of the field rigidly to that of the magnet (RQ3). In the first two types, which have been classified as Emergent Causality models, the levitation is the result of the configuration of the magnetic field created by the YBCO presence. The analog models underlying these representations have a global conception because they include a chain of causal connections, the synthesis of different explored situations, each of which alone does not explain the different aspects of levitation: the field configuration of two magnets maintained with poles counterparts facing; the repulsion between magnets and diamagnetic materials associated with a small reduction of the magnetic flux in the material; the strong deformation of the field lines in presence of a ferromagnetic object (RQ3b). In these models remain open what are the forces developed and the conditions under which they originated (RQ4), highlighting difficulties in the integration of mechanical concepts in electromagnetism (Galili 1998).

The Relational Causal model, on which the third type of students’ representation is based, adopted also in a few representations in which the field penetrates the YBCO, subtends two aspects: the conception that the magnetic field produced by the magnet is present in a limited region of space, is static and rigidly associated to it (Borges, Gilbert 1998); the idea that the YBCO acts directly on the magnet, not by modifying the configuration of the magnetic field (RQ3b). In this case, the recognition, that the interaction magnet-YBCO is different from the interaction between two magnets, is not followed by the structuring of an alternative interpretative model (RQ4).

A fourth emerged relational causality model foresees that the YBCO produces a magnetic image field of that of the magnet. This model is spontaneously activated by the observation of the magnetic levitation phenomenon (RQ1a) and it recalls the model of image field used in literature to discuss the stability of levitation (Arkadiev 1947). It has remained a strong conceptual reference, for those focused on the stability of levitation, and it emerged in the answers of almost half of the sample in the different steps of the path, being expressed in a direct way like “the situation of repulsion between two magnets is realized”, in terms of behavior “acting like two magnets that repulse each other”, as a hypothesis to explore “verify whether TLN YBCO is a magnet” (RQ3). This model impedes the understanding of the dynamic nature of the “image field” produced by the fundamental electromagnetic induction, in order to understand the nature of the Meissner effect (Badía-Majos 2006). The synthesis models discussed above contain elements to overcome such a limit (RQ4).

The significance of the recognition that B = 0 is supported in the present work also by the fact that a large part of the sample (over 2/3) based (1) the analysis of the interaction between a magnet and a ferromagnetic ring with the interposed disc of YBCO, and (2) the characterization of the Meissner effect at the end of the path, on the cancellation of the field inside the superconductor or on its nature of perfect diamagnet (RQ3).

The cancellation of the YBCO resistance at T = TNL was indicated as a relevant aspect by a third of the sample (RQ3). The explicit connection of the electrical and magnetic properties of a superconductor, emerged only in the 10% of students, remained an open knot for the majority (RQ4).

The exploration carried out enabled the recognition of the central role of temperature in the activation of the superconducting state (RQ3), aspect emerged also in the final summary of more than half of the sample, explaining the change to a superconductive state as a phase transition (23/40). This aspect was activated, as well as not fully recognized, even in those who did not have a clear vision of the ordinary phase transitions such as melting and boiling (RQ4). The deepening of the exploration of the superconducting phase transition can be important not only for understanding the Meissner effect, but also for a phenomenological approach to the concept of phase transition.

Given that there were no significant statistical differences in the responses of the two groups of students, these conclusions can refer to the entire sample, since they do not crucially depend on the previous knowledge or on the age. What was mainly different in the two groups was the representation of the magnetic field inside the magnets and the way they stick to the observation outcomes in their sentences.
We stress in conclusion the importance in the experimentations of the active and collaborative learning environment stimulated by the tutorials and the strong motivation created by the challenging phenomenology, confirming the feasibility of the introduction of superconductivity in high school (Viola 2010; Ostermann, Moreira 2010). The results on the characterization of the Meissner effect indicate how to modify the path to affect the knots in the recognition of the phase transition, in the role of the electromagnetic levitation, in the integration into a common framework of electrical and magnetic properties.

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Vector Potential at High School: A Way to Introduce Superconductivity and to Review Electromagnetism

Sara Roberta Barbieri, Dipartimento di Fisica, University of Palermo, Italy
Marco Giliberti, Dipartimento di Fisica, University of Milano, Italy
Claudio Fazio, Dipartimento di Fisica, University of Palermo, Italy

Abstract

Superconductivity is a rich and complex topic that generates great interest and curiosity in high school students. Most of the presentations of superconductivity give a great importance to magnetism. But typically in these presentations the physical role is played by the magnetic field $B$ while the magnetic vector potential $A$ is never mentioned. Moreover the explanation of the quantum phenomena at the base of the superconductivity are often not enough developed and generally given only at a popular level. We think that the key point for a meaningful presentation at high school is the vector potential. In this paper we present a teaching path on the vector potential and a pilot experimentation with two groups of high school students. The introduction of the vector potential is surely very challenging, but we believe that it can be of a great help in reviewing and clarifying many important aspects of basic electromagnetism. In this paper we give the framework of our educational rationale on superconductivity, a brief description of the teaching path on vector potential and some preliminary results of our experimentation.

Keywords: superconductivity, magnetic vector potential, teaching/learning sequence

Our research group in physics education of the University of Milan has been working on the presentation of quantum physics in high school for nearly twenty years. In the last eight years our interest is focused in particular on superconductivity, due to its relations with many subjects of physics, including for example thermodynamics and electromagnetism, and due to the enthusiasm we always found in students. They show a curiosity and a care that are normally difficult to observe in physics sessions: they perform experiments concerning the magnetic levitation with superconductors (Meissner effect) and the measure of critical temperature, they build magnetic tracks for small superconductive trains by their own, they ask many questions and urge their teachers to come to our lab. This encouraged us in the development of an educational path on superconductivity, because we were not satisfied by the presentations we found in literature and on the web.

The educational paths that we have found can be roughly considered made of two parts: (1) a very deep treatment of the phenomenology involved, with many experiments to be performed by the students and (2) a following discursive treatment of superconductivity based on Cooper pairs. This microscopic quantum mechanism, that is the basis of the BCS (Bardeen-Cooper Schrieffer) theory of superconductivity is a so difficult subject that it seems unlikely that a common class could have treated it. In fact, it is usually popularized: this problem is very striking for our group. [Giliberti M., 2008, Giliberti M. et al., 2004]

Therefore two questions immediately appear: 1) Is there anything that we can use to explain superconductivity, at least at a phenomenological level, before using quantum physics? 2) Can we build an educational path for high school to explain BCS theory?

We are working to answer the question 2), but in this paper we write about the question 1) that concerns a phenomenological explanation of superconductivity.

Our aim was to be as rigorous as possible with high school students and we wanted to avoid the use of mathematical tools that students could not have. So, we inspired our path on important and historical works: the two fluid theory of the London brothers [London F. & London H., 1935] and the Pippard's phenomenological description of superconductivity [Pippard A. B., 1953]. Both these works don’t deal...
with the microscopic mechanism of superconductivity. Furthermore, the mathematical tools we chose for students were the same they already use in electromagnetism. (Basically the concepts of flux and circulation). For this reason we believe that this approach is particularly suitable for high school: not only to face superconductivity, but also to review electromagnetism under a new light. In an ultra-simplified description we can say that superconductivity consists essentially of two distinct facts: 1) the resistivity of the sample is zero, 2) inside a superconductor the magnetic field is zero. Both these facts can be explained supposing that inside a superconductor can be generated a super-current, whose density $J_s$ obeys the relation:

$$J_s = -kA,$$  \hspace{1cm} (1.1)

where $A$ is the vector potential, and $k$ a positive constant. Eq.(1.1) resembles so much the Ohm law written as:

$$J = \sigma E,$$  \hspace{1cm} (1.2)

where $E$ is the electric field and $\sigma$ the conductivity. Also, in eq.(1.1) appears the vector potential $A$, that is the key point of our introduction of superconductivity. To avoid the use of the vector potential one is forced to use much more complicated equations, called London equations that we report here below:

$$B + \lambda^2 \nabla \times \nabla \times B = 0.$$  \hspace{1cm} (1.3)

Thus, a certain effort is necessary to introduce $A$, at least because the vector potential is never treated in high school. The little experience that teachers generally have, makes this object unfamiliar, but we will see that this discomfort can be easily overcome. In literature the vector potential is treated only for undergraduate students or teachers [Giuliani G., 2010, Semon M. D. et al., 1996 and Konopinski E. J., 1977], but nothing is presented for high-school students.

Hence, to introduce superconductivity, we need to develop a sequence on vector potential, and we expect that this sequence can help students also to improve their knowledge in electromagnetism. In Fig. 1 we give the general framework of our proposal on superconductivity. In the next section we will expand block 3 (the vector potential block), that is the core of this presentation.

The first part of this paper concerns a detailed description of the path we designed to introduce the vector potential in high school. The second part is a result of the experimentation in two classes of high school students. This experimentation allowed us to clarify the most difficult points of our presentation of vector potential as well as some of the major students difficulties in electromagnetism. Students’ responses were very useful in order to test our path. In fact, what we tried to obtain from the students that followed this first study was a critical reflection about what they experienced. We wanted an evaluation of our work and not an evaluation of the students themselves: for this reason we dedicated a lot of time to oral interviews and to classroom discussion during the lessons.
1. BACKGROUND

Recall of quantum physics:
- Wavelike behaviour of matter: description of light and matter by the same equation
- Statistics: Boltzmann, Bose-Einstein and Fermi-Dirac statistics
- Complex wave functions and De Broglie relations

Electrical conduction:
- Electrical conduction: phenomenological description using $J = \sigma E$
- Microscopic model for the electrical conduction

2. PHENOMENOLOGY

Phenomena description:
- Superconductor of type I and type II
- Dependance of the critical temperature from $B$
- Dependance of the critical temperature from the isotope

Laboratory experiences:
- Measure of the critical temperature of a YBCO sample
- Meissner effect

3. VECTOR POTENTIAL

Recall of the potentials known:
- Gravitational potential
- Elastic potential
- Electrical potential

Magnetic vector potential:
- Introduction of the vector potential
- Example of vector potentials for a uniform magnetic field
- Vector potential in electromagnetism

4. THE TWO FLUID THEORY

Superconductive and normal currents:
- The behaviour of the normal fluid: equation $J = \sigma E$
- The behaviour of super-fluid: equation $JS = -kA$

Phenomena interpretation by the two fluid theory:
- Interpretation of $\rho = 0$
- Interpretation of $B_{\text{EXT}} = 0$

5. THE MICROSCOPIC SUPERCONDUCTIVITY

Waves in a superconductor:
- Analogy between the current in a conductor and in a superconductor
- Matter waves in a superconductor
- The generalized momentum:
- $p = mv + qA$ and the microscopic interpretation of a super-current
- The quantization of the magnetic flux and the charge of the current carrier in a superconductor

Figure 1. Table of the complete framework of the proposal
Method

_How we have presented the vector potential._

In this section we will report the essential lines of our proposal, close to what we have done with students. A teacher knows that it is possible to define the field of the vector potential from which we can get both the electric and magnetic field. The first problem we had to solve was how to define the vector potential in a way suitable for high school students. Typically the vector potential \( \mathbf{A} \) is defined as the vector whose curl is the magnetic field \( \mathbf{B} \). But this definition was out of reach for high-school students.

_The vector potential definition for high school students._

We used the integral version of a vector potential definition, which was the one that Maxwell introduced for the first time in his treatise. [http://archive.org/details/electricandmag02maxwrich].

So we gave our students:

\[
C(\mathbf{A}) = \Phi(\mathbf{B}),
\]

where \( C(\mathbf{A}) \) is the circulation of the vector potential over a closed line \( \gamma \) and \( \Phi(\mathbf{B}) \) is the flux of magnetic field through the surface that has \( \gamma \) as a boundary.

We immediately used this definition to rewrite one of the Maxwell equations in simple terms, as you can see below. From the Maxwell equation:

\[
C_\gamma(E) = -\frac{d}{dt} \Phi(B),
\]

where \( E \) is the electric field, applying the eq. \((2.1)\), we get:

\[
C_\gamma(E) = -\frac{d}{dt} C_\gamma(\mathbf{A}) = -C_\gamma\left(\frac{\partial}{\partial t} \mathbf{A}\right).
\]

For the arbitrariness of \( \gamma \) we finally obtain:

\[
E = -\frac{\partial \mathbf{A}}{\partial t},
\]

From the eq.\((2.4)\) the students can observe that an electric field appears when the vector potential varies with time. But they also know that an electric field appears whenever the magnetic field varies with time (as eq. \((2.2)\) indicates). Hence, both \( \mathbf{A} \) and \( \mathbf{B} \) can be used to describe the electric field, but the expression that contains \( \mathbf{A} \) is simpler and allows you to find the field directly.

_Some applications of the definition._

With students we focused our attention only on a uniform magnetic field, that is the simplest case. Let us consider a uniform outgoing field orthogonal to the surface of the sheet. In order to determine the vector potential, we apply the eq.\((2.1)\). We had to choose a closed line to calculate the circulation. We recalled students what we should always do when we apply the Gauss theorem: (a) we pay attention to the symmetries of the electric field sources (b) we assume that the electric field we want to determine will have the same symmetries of the charge distribution (c) we choose a closed surface that reflects the symmetries of the charge distribution, in order to simplify the calculation and (d) we do the calculation and get the field \( E \). To get the vector potential \( \mathbf{A} \) we have to follow a similar schema. The symmetries of a uniform infinite field are so many that we have a lot of freedom to choose a closed line to calculate the circulation.
First choice of \( \gamma \).

We can fix a point: the point can be the centre of a circle orthogonal to the field lines. We have broken the symmetry of the system with this choice, so we expect that the vector potential we will get, will have a circular symmetry. We calculate \( \mathbf{A} \) starting from eq.(2.1) and with reference to Fig.3. In this image is represented an arrow that indicates the direction and the verse of the vector potential that we guess for symmetry reasons and for simplicity of calculation. We guess that \( \mathbf{A} \) be tangential in each point of the line \( \gamma \) and that its length do not varies along every circle of fixed radius \( r \). If the calculation will conclude consistently we will get the expression of the vector potential and we will find out whether our initial supposition was good.

![Diagram](image)

**Figure 2.** Representation of the first (circular) closed line \( \gamma \)

By applying eq.(2.1) we obtain:

\[
2 \pi r \mathbf{A} = \pi r^2 \mathbf{B}_y
\]

using a circle \( \gamma \) of radius \( r \) to calculate the circulation of \( \mathbf{A} \). We get:

\[
\mathbf{A} = \frac{1}{2} \mathbf{B} r
\]

Since \( \mathbf{A} \) is a vector, we can express its direction and verse using the right hand rule, and we have:

\[
\mathbf{A} = \frac{1}{2} \mathbf{B} \times \mathbf{r}.
\]

In Fig.3 we give a graphical representation of this vector, in a plane orthogonal to \( \mathbf{B} \).
Figure 3. Representation of the vector potential found for the first choice of $\gamma$

The vector $A$ goes along concentric circles and its length increases if its distance from the centre increases. It is increasing indefinitely: we have to keep in mind that here we have an infinite magnetic field, that is an abstract idea of magnetic field, because it could never be realized. After, we will return on this point, while now we want to go on with the path that students followed.

Second choice of $\gamma$.

For the same magnetic field and with the use of the same eq.(2.1) we show that it is possible to determine another expression for the vector $A$ that works good as the previous one. Now we brake the symmetry by an infinite straight line. In this symmetry a good closed line $\gamma$ can be a rectangle that has the infinite line as axis of symmetry. In Fig.4 you can see the new choice of $\gamma$ and the ansatz for the vector potential disposition. This time we imagine that the length of the vector does not change at a fixed distance from the axis of symmetry and we are forced to suppose two opposite directions for $A$ at the opposite sides of the axis, otherwise the circulation will give zero as a result.

Figure 4. Representation of the second (rectangular) closed line $\gamma$

As in the previous case we apply eq.(2.1) and we obtain:

$$2hA = 2hx B,$$

and hence:

$$A = Bx.$$

We can represent graphically the result, as in Fig.5.
We found out a second different behaviour for $A$: in this case, the arrows are positioned suggesting something that is “flowing” in two opposite directions. Even in this second calculation we got a vector that increases indefinitely. From what we have seen so far we can conclude that a given magnetic field can give at least two different vector potentials.

A brief comment for teachers: indeed, a given magnetic field can give infinite different vector potentials: this is mathematically true, this is called gauge invariance. But the problem was: how can we tell to high school students about gauge invariance? In other words, what is the physical meaning that you can give to the fact that many different fields $A$ describe the same magnetic field?

We answered this question to students saying that it is possible to overcome the ambiguity in the determination of $A$ by clarifying which is the current that generates a certain magnetic field. A teacher knows that an approach like this is equivalent to a particular gauge choice: if you say that the current distribution fixes $A$ is equal to say that you choose the Coulomb gauge: we chose this intuitive gauge to work with students.

We gave them the Coulomb gauge as a sort of rule: “if you want to have information about a vector potential, starting from a magnetic field, you have to find out which is the current distribution that can generate it. From the currents you can guess the vector potential, because it follows them (in simple cases it is more intuitive, than in others!)”

Only in a second step a student will apply eq.(2.1) to get $A$. If the currents become our guide, we can easily understand the two different expressions for $A$. Let us see how, in the next paragraphs.

**The uniform field generated by a solenoid.**

The first and simple way to generate a uniform magnetic field, in a circular region, is a current-carrying solenoid, as you can see in Fig.6. Here is represented the section of the solenoid by the circle in bold and the current is flowing along that line. Thus, we can imagine $A$ tangential in each point of that circle (and in each point of the infinite possible concentric circles).
In the Fig. 6 we can see the section of a solenoid of radius $R$ and two different closed lines $\Gamma$ and $\Gamma'$. If we calculate the circulation of $A$ along the line $\Gamma$ we find exactly the vector potential already found in the first case, that of the central symmetry. Furthermore, we can see that using the line $\Gamma'$ we can get information on the vector potential outside the solenoid, too. The calculation is very simple and we omit it. Instead, we report the behaviour of the vector potential, so that it is possible to make a comparison with that of eq.(2.7).

**Figure 6.** Section of a solenoid (in bold) and two different paths $\Gamma$ and $\Gamma'$

In Fig. 7 we can see that the vector potential in this real physical case does not increase indefinitely, but increases until the solenoid is reached and then it decreases away from the source of $A$ itself.

**Figure 7.** Representation of $A$ inside and outside the solenoid

In this real physical case, the vector potential does not increase indefinitely. Instead, it increases until the solenoid is reached and then it decreases away from the source of $A$ itself.

**The uniform field generated by two parallel planes carrying current.**

A second way to generate a uniform field is by two parallel planes along which a current flows as you can see in Fig. 8, where the arrows represent the verse of the current.
We can also note that the current distribution has a symmetry of reflection with respect to an axis, i.e. the same symmetry that we found previously for the second expression of $A$.

With simple considerations, that we omit for shortness, it is possible to show that a distribution like that of Fig. 8 generates a uniform field inside the planes. It is certainly useful for students to see the demonstration or to try to make it, once at least.

We then apply the relationship (2.1), referring to Fig. 9, using two different closed lines $\Gamma$ and $\Gamma'$, the first completely inside the planes, while the second one crossing the planes. The planes are represented in section by the two bold arrows.

With very similar calculations to those of the previous case, we obtain for $A$ the vector represented in Figure 10: its expression inside the planes is exactly the same of that of eq.(2.9).
A brief comment to what we found.

First, a clarification: neither in this case nor in the previous one we considered how the currents have been generated and we neglected all the technical details, because we want to focus on the effect of the currents rather than on the currents themselves. Second, we want to stimulate a reflection on the fact that in the external region of the two configurations we considered, \( \mathbf{B} \) is always null (or negligible). But however we can describe \( \mathbf{A} \) in two different ways: a decreasing vector that tends to zero, in the first case and a constant vector in the second case. In our experimentation the path on vector potential ended with the visit of a website in which students could see a representation of magnetic fields and vector potentials of a lot of current distributions. [http://www.falstad.com/mathphysics.html]

How we have performed the experimentation.

The present introduction of the vector potential is the first step of a design based research. Thus, the aim of this first experimentation with students was to understand the learning knots and students’ difficulties in order to design the second step of the research. For this reason we gave more room to the interviews rather than to written tests whose aim is more centred on the evaluation of the students’ knowledge. We had two groups of high school students, 18 years old. Each of them was attending the last year of an high scientific school. The groups were very different in motivation and previous knowledge, despite they had the same age, they followed the same kind of school and they already studied the Maxwell equations. We will define group 1 the motivated one, and group 2 the other.

Group 1

In this group there were 25 students from different classes and schools. They came to our laboratory because they voluntarily participated to PLS project (scientific degree plan). All of them were keen on mathematics and physics. The lessons were held at the university, in the afternoon, in extracurricular hours. They followed a complete laboratory on superconductivity in a total of 24 hours. In this context the lesson on vector potential was held in a single afternoon for about 4 hours. In a second afternoon students applied \( \mathbf{A} \) in order to develop the two-fluid theory, using the London brothers equations.

Group 2

This group was formed by 29 students from a private high school class and the lessons were held during the curricular hours. They spent about 10 hours following mainly a presentation on vector potential to refresh the Maxwell equations and the basis of electromagnetism. Initially, our idea was to apply the vector

Figure 10. representation of \( \mathbf{A} \) inside and outside two parallel current-carrying planes

From Figure 10 we note that outside the planes we find a uniform vector potential.
potential to the study of superconductivity, but we had to revise the basic concepts of electromagnetism so long that we did not had time left.

The sequence on vector potential was the same, but group 2 took three times more time than group 1. From informal oral interviews with the group 1 we identified some of the main learning knots of our presentation on vector potential. Semi-structured oral interviews involved students of group 2: we interviewed two students at the same time, usually starting with a problem or a general question and then following their reasoning. The problems, or questions, were similar, from once with the other, and often they were in relation with the lesson just finished. We report below typical starting problems/questions that we used.

1. Imagine a infinite plane along which is flowing a constant current. What can you say about the electric and magnetic fields around the plane?
2. Imagine an infinite wire carrying a steady current. What can you say about the electric and magnetic fields around the wire?
3. What is a magnetic field?
4. What is an electric field?
5. Are you able to tell the difference between an electric and a magnetic field?
6. Is there a magnetic field in this room? How can I find out?

As the reader can see, the difficulty of the questions proposed decrease from point 1) to point 6). This is because we reported here the chronological order in which we asked them to the students, on average. In the next section we report some of the more interesting answers of the students, or parts of dialogue.

**Results**

**Students of group 1 – Motivated students**

Students of this group used mathematics so easily that most of them would prefer dealing with differential equations than with the integral ones. Here below we report an excerpt of a dialogue among the teacher and two students. What we report is very short but contains a lot of information. The students were asked to describe the field lines of the vector potential around a cylinder carrying, on its surface, an electric current in the direction of the axis of the cylinder.

S1: I remember that the field lines follow the current that generates $A$ itself.

T: What happens to $A$ if you move away from the currents which generated $A$ itself?

S1: I dare say that $A$ decreases, but $A$ is counterintuitive... but I remember that it increases...so I don’t know...

S2: It’s difficult, because with $A$ you can’t use imagination! You have just to use it to do calculations.

T: What do you think about the vector potential?

S2: I think it was a very interesting topic, I like it. There is a thing that for me is difficult to accept: the fact that the vector potential can be defined in many different ways and not only but a constant, as it is for the scalar potential.

**Students of group 2 – Not motivated students**

Students of this group had already seen Maxwell equations during the last months. When we started with our sequence we tried to use basic mathematical tools such as circulation and flux, but they were not able to follow the teacher’s explanation. So we spent part of our time to review these concepts, thus we collected many information about their difficulties. This is what we briefly summarize here, above all the concepts related to vector potential.
Flux
The flux of a vector does not represent for students something that crosses an imaginary surface but something that “happens” to a real surface. From the following dialogue it emerges clearly:

T: Imagine to have a river: each part of it has a certain velocity, so we can define a field of velocities. What surface can I refer to, if I want to determine the flux of the river through a certain surface?
S1: To the surface of the river, that is its highest part.
T: So, is the surface a part of the river?
S1: Yes, it is!
T: And what do you imagine when I say “water flow through a surface?”
S2: I imagine water moving on that surface, in a lot of different directions.

Circulation
The circulation is a concept very difficult for students, they do not perceive the physical sense of this operation and they are not able to give a meaning to the terms of the integral. Here below there are two dialogues.

The first
T: Have you looked for the definition of circulation?
S1: Which one? The Maxwell equations?
(The teacher explains the difference between a theorem and a definition)
T: Others?
S2: Well, I didn’t know the definition of the circulation of a vector, so I used google...
T: We have been doing this during the last lessons...
S2: Yes we did circulation... but not for a vectorial field...
T: ...oh... and for what else?

The second
T: What is the meaning of performing the circulation integral?
S3: The evaluation of an area?

Magnetic field
The magnetic field is often confused with the electric field. Initially we noticed that the interviewed students used the two terms (electric and magnetic) alternatively, as if they had the same meaning. We tried to force the students attention on the concept that they were expressing and then we discovered they really did not differentiate the concept of the electric field from that of magnetic field. After a certain number of oral interviews we asked students during a lesson if they knew the difference between an electric and a magnetic field. They answered simply “No” and someone specified “I never know if in a certain physical situation there will be a magnetic or an electric field”. We report below parts of typical dialogues on this topic.

The first
T: What generates a magnetic field?
S1: A charge?
S2: An electric field?
T: Is there a magnetic field in this room?
S1: ...(He does not answer)
S2: I don’t know...

The second
T: If I consider a simple circuit, with a battery and a led, which are the fields involved in this situation?
S2: If there is a circuit, then there will be a magnetic field, but if the wire is insulated by rubber, the magnetic field does not get out... otherwise our houses would be full by magnetic fields!

Long wire carrying a steady current
This question is not so simple, but we asked to students to answer, in order to collect information about their way of reasoning. We found quite often that they ignore the presence of the magnetic field, or simply they remember concentric circles around the wire which become the paths of a charge that is close to the wire. In some other cases students image an attraction between wire and charge, but they are not able to justify their hypothesis: they often think to an attraction between two charged bodies (independently on the sign of the charges), where the wire is seen as a line of moving charges, rather than a neutral object. Here below we report only some of the dialogues among teacher and students.

T: What is the field around a wire carrying a steady current?
S1: ...an electric field...?
T: What is an electric field in your mind?
S1: An electric shock!
T: Coming back to the situation of a charge near a wire carrying a steady current: do you think that a charge can feel something?
S1: Oh, yes, because the current is made up of charges!
S2: Yes! the charge will try to be closer to the wire in order to re-charge itself more and more!
S3: In my opinion the charge runs along the circular field lines of the wire.

Discussion and conclusions
The interviews with students allowed us to focus on what is difficult in electromagnetism and what can be improved in our path. Starting our discussion with the results of the motivated group of student we immediately can observe two important things. The first thing pertain our approach in the definition the vector potential. We said that we defined the vector potential like Maxwell did when he introduced \( \mathbf{A} \) for the first time.

Following the Maxwell’s reasoning we can perceive the necessity of the existence of \( \mathbf{A} \), but we can not appreciate its physical sense. It would be important to give a definition, or a property, beside the previous one to help them in clarifying the physical sense of the vector potential. Thus, we think that it should be important give the students a more constructive definition of \( \mathbf{A} \). A student should arrive to explicit \( \mathbf{A} \) in a relationship; this is possible to do, even for high school students. It is possible by carrying out an analogy with the scalar potential \( V \). We start from the scalar potential, generated by a charge \( Q_1 \) placed in the position \( \mathbf{r}_1 \), in a point that is placed in the position \( \mathbf{r} \):

\[
V(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{|\mathbf{r}_1 - \mathbf{r}|}.
\]  

(4.1)

Then we extend the potential for \( N \) charges \( Q_2, Q_3, ..., Q_N \) and we obtain:
If the distribution of charge is not discrete, but continuous, we should replace the sum with an integral and we finally write:

\[ V(\mathbf{r}) = \frac{1}{4\pi \varepsilon_0} \int \frac{\rho(\mathbf{r}')dV'}{|\mathbf{r} - \mathbf{r}'|}. \]  

(4.3)

where \( \rho(\mathbf{r}')dV' \) is the infinitesimal charge placed in \( \mathbf{r}' \). This is what we can write for the scalar potential, whose sources are charges. In the case of vector potential we can think that its sources are currents and we can write for analogy the following expression:

\[ \mathbf{A}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \frac{\mathbf{j}(\mathbf{r}')dV'}{|\mathbf{r} - \mathbf{r}'|}. \]  

(4.4)

where \( \mathbf{j}(\mathbf{r}')dV' \) is the infinitesimal element of current. If the vector potential is defined by the (4.4), it satisfies the (2.1) and vice versa. We do not dwell on this point, because it would be too long. But we want to stress the importance of giving students a definition of \( \mathbf{A} \) based on its sources in the same way they we have done for the scalar potential. This would help them to recognize that vector potential is well defined and physically meaningful as the scalar potential is.

In the presentation of vector potential that we reported in this paper we did not give room to this analogy and we limited the definition to eq.(2.1). We think it is mainly for this reason that students were upset when they found out two different \( \mathbf{A} \) for the same \( \mathbf{B} \). In the second step of our presentation we tried to give a description of \( \mathbf{A} \) as much similar as possible to that of the electrical potential \( V \). In this way we hope the students might review their previous knowledge and better ingrain the new concepts.

The second important knot of our presentation, that we deduce from the interviews, is related to the word “counterintuitive” that good students used a certain number of time to characterize \( \mathbf{A} \). When we presented the vector potential we dedicated much time in some application of the eq.(2.1) to obtain \( \mathbf{A} \) for a uniform \( \mathbf{B} \), but we did not dwell the explanation of the currents that generated \( \mathbf{B} \). It’s likely for this reason that the students attributed to \( \mathbf{A} \) a counterintuitive behaviour: if we recall Fig.3 or Fig.5, we can see that \( \mathbf{A} \) seems to increase indefinitely. Therefore students mistook the centre of symmetry of the closed line with the source of the field! This happened due to the fact that we did not described a physical situation (\( \mathbf{B} \) was infinitely extended). Let’s look instead to Fig.7 or Fig.10, where \( \mathbf{B} \) is a finite region of the space (inside a solenoid, or inside two plans). Here, the section of the solenoid is present in the graph, so the current is well represented, and hence the physical sense becomes clear: in this way students can associate \( \mathbf{A} \) to the currents.

Unfortunately this latter part has not be treated enough, for the few time we had and because it was the first time we experimented the sequence. Again, the problem that students perceive the vector potential as counterintuitive is strongly related with the definition of the vector potential of eq.(2.1). These two difficulties are therefore related to each other and has to be studied in deep in the second step of our research. The results we obtained from the not motivated group were very important to evaluate the level reached in electromagnetism of the most of the high school students. This is quite worrying but it makes us believe that it is necessary that students have time to review electromagnetism and to apply mathematical tools in solving problems. We think that \( \mathbf{A} \) could be very useful for this purpose, especially if the curriculum of the students contains the scalar potential: in this way they could develop an analogy between the two potentials.

References


Report and Recommendations on Multimedia Materials for Teaching and Learning Electricity and Magnetism

Debowska  
University of Wroclaw (PL)  
R. Girwidz  
Ludwig-Maximilians-Universität München (DE)  
T. Greczylo  
University of Wroclaw (PL)  
A. Kohnle  
University of St. Andrews (UK)  
B. Mason  
University of Oklahoma (US)

L. Mathelitsch  
University of Graz (AT)  
T. Melder  
University of Louisiana, Monroe (US)  
M. Michelini  
University of Udine (IT)  
I. Ruddock  
University of Strathclyde (UK)  
J. Silva  
Escola Secundária Henrique Medina (PT)

Abstract

The report presentation done by the member of the reviewing group was a part of a MPTL Symposium organized in the course of WCPE. During the symposium four talks related to the different uses of multimedia in the teaching and learning of physics were presented. The symposium was held by members of the MPTL group and covered four areas of interest: modeling and simulation, remote laboratories, video, and dissemination. We provided a review of the state of the art of each of the areas discussed, together with our vision of how the topic contributes to better teaching and learning of physics. Every year, the MPTL board carries out an evaluation of multimedia resources for teaching and learning a particular field of Physics. The paper presents the report on this year’s evaluation, which covered the field of Electromagnetism and is meant to bring to the readers’ attention to the described work and the recommended materials.

Keywords: MPTL, multimedia, resources, electromagnetism

Introduction

Information technology has become ubiquitous in the lifetime of our current students. Teaching and learning practices are impacted by the current wide selection of multimedia resources. Many educators and researchers are developing, and using, a variety of educational materials that make use of simulations, virtual laboratories, videos of real and animated experiments, and online tutorials based on well-established didactic methods [1], [2]. In physics we have many collections of high-quality resources freely available and easily accessible via the internet.

This report presents the results of a peer review of open access/open source multimedia and technology-based learning materials devoted to topics in electricity and magnetism. The peer review is part of a continuing series of annual reviews, started in 2002, carried out by an international group of physicists associated with MPTL Conference. Each year, one physics area such as Mechanic, Optics and Waves, Solid State, Nuclear and Particle Physics, Electricity and Magnetism, Statistical and Thermal Physics is chosen for review. The goals of these review processes are to identify quality media-based teaching resources and to encourage use of them.
**Process**

- The evaluation process in this year’s review consisted of four main steps:
  - gathering a broad list of resources,
  - sorting out quality materials suitable for reviews,
  - reviewing and reporting noteworthy items,
  - providing an overview of the review results.

The creation of a preliminary list of resources for review took advantage of a number of tools. The search started with the list created from the previous review on Electricity and Magnetism carried out in 2005 and additional items were added through web searches by students at the University of Oklahoma and comparison with the online resource databases in MERLOT (280 resources) and ComPADRE (680 resources). There was significant overlap between all of these sources, resulting in a preliminary list containing about 1,000 items. Many of these were individual resources that are part of larger collections. In the next step of the collection and review process, these individual resources are gathered into a single item for final review.

The filtering process consisted of removing items that:

- could no longer be found,
- were no commercial (for-fee),
- were copies or mirrors from other web sites were removed,
- had obvious physics errors,
- with little or no multimedia

resulted in about 240 resource collections that were suitable for potential review. One of us (Mason) sorted these resources into four main categories to determine which would be suitable for a full review. The resultant categories and the number in each were:

- do not review (140),
- low priority review (35) – these items had some interesting aspects but were of lower potential quality,
- high priority review (54) – these items were assigned to reviewers,
- interesting examples (9) – a few other items were kept as interesting examples mostly video collections (seen as limited potential for student engagement) and examples of materials with physics errors but ranked highly in Google searches.

The high priority review resource collections were each assigned to two or more reviewers using an online review process hosted on ComPADRE. The review rubric used here has been described in previous reports [3]. It includes three main aspects of quality multimedia learning resources: Motivation for using the resource (ease of use, attractive layout, stated purpose, and stated use), Quality of Content (relevance, scope, accuracy), and the didactic Methods and Context (flexibility, targeted audience, pedagogy, feedback, and documentation). Each area is rated on a 5-point scale, and overall ratings in each category and for the total review are given.
Resources

The table below presents all high priority resources reviewed and those kept as interesting examples together with information about covered topic(s) and some short comments. Only 8 of them were highly ranked by one or more reviewers and they are marked with colors and presented in the table together with additional information.

<table>
<thead>
<tr>
<th>URL</th>
<th>Topic(s)</th>
<th>Short comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://amrita.vlab.co.in/?sub=1&amp;brch=192">http://amrita.vlab.co.in/?sub=1&amp;brch=192</a></td>
<td>Magnetism, Charges, Resistance</td>
<td>Device and experiment simulations, with notes, assessments, and references</td>
</tr>
<tr>
<td><a href="http://bestphysicsvideos.blogspot.com/search/label/Electricity%20and%20Magnetism">http://bestphysicsvideos.blogspot.com/search/label/Electricity%20and%20Magnetism</a></td>
<td>E&amp;M</td>
<td>Video Channel, many sources</td>
</tr>
<tr>
<td><a href="http://canu.ucalgary.ca/map/content/circuitbuilder/basic/simulate/practice/">http://canu.ucalgary.ca/map/content/circuitbuilder/basic/simulate/practice/</a></td>
<td>DC Circuits</td>
<td>Circuit Board Simulator. Demo available</td>
</tr>
<tr>
<td><a href="http://canu.ucalgary.ca/map/content/energy/work_kinetic/simulate/elfield/applet.html">http://canu.ucalgary.ca/map/content/energy/work_kinetic/simulate/elfield/applet.html</a></td>
<td>Charges, Electric Field</td>
<td>Simulation of charge motion in a field</td>
</tr>
<tr>
<td><a href="http://canu.ucalgary.ca/map/content/fields/electric/dipole/simulate/applet.html">http://canu.ucalgary.ca/map/content/fields/electric/dipole/simulate/applet.html</a></td>
<td>Electric Field</td>
<td>Simulation of fields due to electric charges</td>
</tr>
<tr>
<td><a href="http://canu.ucalgary.ca/map/content/fields/magnetic/dipole/simulate/applet.html">http://canu.ucalgary.ca/map/content/fields/magnetic/dipole/simulate/applet.html</a></td>
<td>Magnetism</td>
<td>Magnetic Field simulator, Current loops</td>
</tr>
<tr>
<td><a href="http://canu.ucalgary.ca/map/content/fields/magnetic/point/simulate/applet.html">http://canu.ucalgary.ca/map/content/fields/magnetic/point/simulate/applet.html</a></td>
<td>Magnetic Field</td>
<td>Illustration of the Magnetic Field from straight wire</td>
</tr>
<tr>
<td><a href="http://canu.ucalgary.ca/map/content/force/elcrgmn/simulate/exb_thomson/applet.html">http://canu.ucalgary.ca/map/content/force/elcrgmn/simulate/exb_thomson/applet.html</a></td>
<td>Charges, E&amp;M Fields</td>
<td>Charge motion in crossed electric and magnetic fields</td>
</tr>
<tr>
<td><a href="http://courseweb.stthomas.edu/apthomas/SquishyCircuits/index.htm">http://courseweb.stthomas.edu/apthomas/SquishyCircuits/index.htm</a></td>
<td>Circuits</td>
<td>Experiment videos, simple circuits</td>
</tr>
<tr>
<td><a href="http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/#item">http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/#item</a></td>
<td>Charges, Circuits</td>
<td>Flash animations and short tutorials on E&amp;M (All intro physics topics covered.)</td>
</tr>
</tbody>
</table>

The collection of tutorials that include theory and a simulated experiment, as well as a self-evaluation for students test their understanding, exercises for exploring the experiment, and references. One reviewer felt the combination of theory, simulation, activities, and tutorials are very noteworthy and high quality. The second reviewer felt that the simulated experiments are too structured and “cookbook” for effective learning.
<table>
<thead>
<tr>
<th>URL</th>
<th>Description</th>
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<tr>
<td><a href="http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html">http://hyperphysics.phy-astr.gsu.edu/hbase/emcon.html</a></td>
<td>E&amp;M</td>
</tr>
<tr>
<td><a href="http://jacob.fe.uni-lj.si/eng/index.html">http://jacob.fe.uni-lj.si/eng/index.html</a></td>
<td>E&amp;M Fields, Circuits</td>
</tr>
<tr>
<td><a href="http://jakobvogel.net/legacy/index.php?url=physics/index.xml">http://jakobvogel.net/legacy/index.php?url=physics/index.xml</a></td>
<td>E&amp;M Fields, Circuits</td>
</tr>
<tr>
<td><a href="http://lectureonline.cl.msu.edu/~mmp/applist/applets.html">http://lectureonline.cl.msu.edu/~mmp/applist/applets.html</a></td>
<td>Charges, E&amp;M Fields, Lorentz Force</td>
</tr>
<tr>
<td><a href="http://matterandinteractions.org/Content/Materials/Videos/SurfaceCharge.mov">http://matterandinteractions.org/Content/Materials/Videos/SurfaceCharge.mov</a></td>
<td>Charges, current</td>
</tr>
<tr>
<td><a href="http://micro.magnet.fsu.edu/electromag/index.html">http://micro.magnet.fsu.edu/electromag/index.html</a></td>
<td>E&amp;M applications, circuits</td>
</tr>
<tr>
<td><a href="http://ngsir.netfirms.com/">http://ngsir.netfirms.com/</a></td>
<td>Circuits</td>
</tr>
<tr>
<td><a href="http://online.physics.uiuc.edu/courses/phys212/gtm/simulations/index212.html">http://online.physics.uiuc.edu/courses/phys212/gtm/simulations/index212.html</a></td>
<td>E&amp;M Fields, Currents</td>
</tr>
<tr>
<td><a href="http://online.supercomet.no/">http://online.supercomet.no/</a></td>
<td>Conduction, Superconductivity</td>
</tr>
<tr>
<td><a href="http://oyc.yale.edu/physics/phys-201">http://oyc.yale.edu/physics/phys-201</a></td>
<td>Course: E&amp;M, Circuits, Waves, Quantum</td>
</tr>
</tbody>
</table>

The set of resources, the use of videos for student exploration in a learning cycle is noteworthy. The explorations provide the learning goal, prior knowledge, and one or more prediction and follow-up questions. Simple experiments using common materials are used. The multimedia use is limited to videos but these are well designed for the learning goals.
The collection of materials provides a series of research-based interactive environments for students to explore different physics topics. Each of the simulations includes a number of lesson plans created by instructors and researchers on the PhET team. The reviewers had different opinions of the materials. All reviewers noted the open, flexible, and exploratory nature of the resources, although one reviewer felt a need for more structure. The concern was expressed that inaccurate student understandings could be reinforced by the models, although the PhET researchers study the student use of the simulations to avoid this problem. The algorithms and approximations used in the program are not given. In the E&M materials there are four main noteworthy simulations (Circuits, Faraday, E&M Fields, E&M Waves) with multiple versions of some of these provided for the use of different audiences.

<table>
<thead>
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<th>URL</th>
<th>Topics</th>
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<td><a href="http://physics.bu.edu/%7eduffy/semester2/">http://physics.bu.edu/%7eduffy/semester2/</a></td>
<td>E&amp;M All topics</td>
<td>Simulation-illustrated tutorials</td>
</tr>
<tr>
<td><a href="http://resources.schoolscience.co.uk/BritishEnergy/11-14/index.html">http://resources.schoolscience.co.uk/BritishEnergy/11-14/index.html</a></td>
<td>Circuits</td>
<td>Tutorial with simulation-based activities</td>
</tr>
<tr>
<td><a href="http://ressources.univ-lemans.fr/AccesLibre/UM/Pedago/physique/02/mnelectricite.html">http://ressources.univ-lemans.fr/AccesLibre/UM/Pedago/physique/02/mnelectricite.html</a></td>
<td>Electrostatics</td>
<td>In French</td>
</tr>
<tr>
<td><a href="http://ressources.univ-lemans.fr/AccesLibre/UM/Pedago/physique/02/mnelectro.html">http://ressources.univ-lemans.fr/AccesLibre/UM/Pedago/physique/02/mnelectro.html</a></td>
<td>Magnetostatics</td>
<td>In French</td>
</tr>
<tr>
<td><a href="http://techtv.mit.edu/collections/physicsdemos/videos?view=list">http://techtv.mit.edu/collections/physicsdemos/videos?view=list</a></td>
<td>E&amp;M all topics</td>
<td>Video experiments with explanations (Wide range of physics topics.)</td>
</tr>
</tbody>
</table>

The collection of physics explorations based on interactive simulations. The simulations are easy to run using the intuitive interface. The recommended explorations will help learners focus on the important physics the topics covered. The use of Easy Java Simulations provides users with the capabilities of viewing and modifying the source.

The resource provides a focused, simple introduction to circuits suitable for primary and secondary students. The tutorial includes theory, virtual experiments, and self-tests for learners. The simulation is interactive, although it is a little hard to construct circuits at times. Many exploratory „challenge” problems are available for students to use, although one reviewer felt some problems were too scripted.
The series of high quality simulations and illustrations of all E&M topics. There is a particular focus on visualization of fields. In many of the illustrations there is little or no interactivity for the learner, but other simulations allow more exploration. Also of note, this is part of an Open Courseware course with all activities, labs, etc. (http://ocw.mit.edu/courses/physics/8-02-physics-ii-electricity-and-magnetism-spring-2007/index.htm) providing a complete didactic context for the multimedia resources.

http://webphysics.davidson.edu/aplets/ibe/default.html Charges, E&M Fields Interactive video experiments with simulations

http://webphysics.davidson.edu/physletprob/ch7_in_class/in_class7_2/default.html E&M Fields, Charges, Currents Simulation-based illustrations of E&M physics

http://webphysics.davidson.edu/physletprob/ch7_in_class/in_class7_3/default.html Charges, Dielectrics, Metals Simulation-based illustrations of charges and materials

http://webphysics.davidson.edu/physletprob/ch9_problems/default.html E&M Fields, Induction Simulation-based exercises and problems

http://wps.aw.com/aw_young_physics_11/13/3510/898593.cw/index.html E&M all topics Students tutorials and explorations with simulations


http://www.article19.com/shockwave/oz.htm Circuits Animated simulator for simple circuits

http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/straw.htm Charge, Current Video experiment

http://www.batesville.k12.in.us/physics/PHYNET/e&m/efields&potential/efgApplet/EFIELDGame.html Charges, Electrostatics Simulation-based game to find charge distributions

http://www.cco.caltech.edu/~phys1/java.html Circuits, E&M Fields, Charges Illustrations of E&M Concepts

http://www.compadre.org/osp/search/search.cfm?gs=224&b=1&qc=Modeling E&M all topics Simulation and curricular material packages, open source

The collection of different resources from different authors all using the Easy Java Simulations platform. The type and quality of the content varies, but most are quite good. Theory and student activities are embedded with many, but not all, of the EJS models. One noteworthy aspect of the EJS environment is that all models can be opened and modified as needed. This also makes clear the algorithms and approximations being made.

http://www.concord.org/activities/subject/physics Electrostatics, Current Multimedia-based tutorials with student assessment and feedback

http://www.falstad.com/mathphysics.html E&M Fields Simulations with a wide range of examples
<table>
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<tr>
<th>URL</th>
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<td>Electrostatics</td>
<td>Illustrated introduction to electric potentials of charges</td>
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<td><a href="http://www.jhu.edu/~virtlab/logic/log_cir.htm">http://www.jhu.edu/~virtlab/logic/log_cir.htm</a></td>
<td>Digital Circuits</td>
<td>Tutorial and digital logic circuit builder</td>
</tr>
<tr>
<td><a href="http://www.magnet.fsu.edu/education/tutorials/java/index.html">http://www.magnet.fsu.edu/education/tutorials/java/index.html</a></td>
<td>E&amp;M Fields, Induction, Charges</td>
<td>Short tutorials with simulations and animated illustrations</td>
</tr>
<tr>
<td><a href="http://www.mindset.co.za/learn/s28/t15535">http://www.mindset.co.za/learn/s28/t15535</a></td>
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<td>Video lessons and supplemental materials</td>
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<td><a href="http://www.montereyinstitute.org/courses/Introductory%20Physics%20II/nroc%20Prototype%20Files/coursestartc.html">http://www.montereyinstitute.org/courses/Introductory%20Physics%20II/nroc%20Prototype%20Files/coursestartc.html</a></td>
<td>E&amp;M all topics</td>
<td>Multimedia textbook and student learning resources, problems, self-assessments. (All intro physics topics.)</td>
</tr>
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<td><a href="http://www.ndt-ed.org/EducationResources/HighSchool/highschool.htm">http://www.ndt-ed.org/EducationResources/HighSchool/highschool.htm</a></td>
<td>Circuits, Magnetism</td>
<td>Tutorial Material with animated illustrations</td>
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<td><a href="http://www.nhn.ou.edu/walkup/demonstrations/WebAssignments/index.html">http://www.nhn.ou.edu/walkup/demonstrations/WebAssignments/index.html</a></td>
<td>Charges, E&amp;M Fields</td>
<td>Animation-based exercises and questions</td>
</tr>
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<td><a href="http://www.physicsclassroom.com/Class/circuits/">http://www.physicsclassroom.com/Class/circuits/</a></td>
<td>Currents, Circuits</td>
<td>Hyper-linked tutorial</td>
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<tr>
<td><a href="http://www.physicsclassroom.com/Class/electastics/">http://www.physicsclassroom.com/Class/electastics/</a></td>
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<td>Hyper-linked tutorial</td>
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<tr>
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<td>E&amp;M all topics</td>
<td>Online textbook with simulations, Spanish</td>
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<td><a href="http://www.surendranath.org/Apps.html">http://www.surendranath.org/Apps.html</a></td>
<td>E&amp;M Fields, Charges</td>
<td>Simple simulations of fields and charges</td>
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<td>Charges</td>
<td>Tutorial with virtual experiments and exploration</td>
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<td><a href="http://www.udel.edu/ghw/circuit-simulator/">http://www.udel.edu/ghw/circuit-simulator/</a></td>
<td>DC Circuits</td>
<td>Simple circuit simulator with resistors and wires</td>
</tr>
<tr>
<td><a href="http://www.virrlab.virginia.edu/VT/contents.htm">http://www.virrlab.virginia.edu/VT/contents.htm</a></td>
<td>Circuits, E&amp;M Fields</td>
<td>Video-based explanations of E&amp;M, with a focus on nanoscience</td>
</tr>
<tr>
<td><a href="http://www.virtual-oscilloscope.com/">http://www.virtual-oscilloscope.com/</a></td>
<td>Oscilloscope</td>
<td>Virtual oscilloscope lab simulation</td>
</tr>
<tr>
<td><a href="http://www.walter-fendt.de/ph14e/index.html">http://www.walter-fendt.de/ph14e/index.html</a></td>
<td>Magnetic Fields, Circuits, Induction</td>
<td>Simulations of circuits and virtual experiments</td>
</tr>
</tbody>
</table>
**Conclusions and further plans**

The review process found items of significant value for educational purposes. Moreover the review rubrics and the reviewers’ expectations together set a high bar for recognition as high-quality multimedia resources. The discrepancies between reviews were mostly the result of the different didactic expectations of the reviewers. This aspect might be of a potential topic for the investigation. These differences were usually based in different views of the proper balance between student-controlled explorations and more teacher-scaffolded learning exercises.

Few new examples of simulation-based multimedia learning resources for physics were discovered in this review. The reason might arise from flaws in the search process or too-restrictive views on quality, interactive multimedia. It might also be that the materials available from the existing developers are meeting instructors’ needs. This might be a mature field with little motivation for new developers to create more materials.

Currently, a great deal of work is going into the creation of videos and online course material based around videos. Few such video collections were included in this review because most are simply filmed lectures or demos. They are online examples of face-to-face pedagogies with limited effectiveness. Videos such as these have their uses but require a great deal of context.

A search was made for mobile applications (tablet and phone-based) but the review process found very few good examples for E&M. Most were simply vocabulary lessons and other lower-level learning activities.

**References**


Understanding the Nature of Science and Nonscientific Modes of Thinking in Gateway Science Courses

Calvin Kalman, Concordia University, Montreal, Canada
Marina Milner-Bolotin, University of British Columbia, Vancouver, Canada
Mark W. Aulls, McGill University, Montreal, Canada
Elizabeth S. Charles, Dawson College Montreal, Canada
Gul Unal Coban, Dokuz Eylul University, Izmir, Turkey, Corresponding author,
Bruce Shore, McGill University, Montreal, Canada
Tetyana Antimirova, Ryerson University, Toronto, Canada
Juss Kaur Magon, McGill University Montreal, Canada
Xiang Huang, Concordia University Montreal, Canada
Ahmed Ibrahim, McGill University Montreal, Canada
Xihui Wang, McGill University Montreal, Canada
Gyoungho Lee, Seoul National University, Seoul, South Korea
Ricardo Lopes Coelho, University of Lisboa, Lisbon, Portugal
Dang Diep Minh Tan, Tra Vinh University, Tra Vinh Province, Vietnam
Guopeng Fu, University of British Columbia, Vancouver, Canada

Abstract

This work consists of two studies at two different institutions. At each institution students in two sections were taught by the same instructor. In each study, in one section [experimental group] we introduced a set of reflective writing and critique-writing activities, and collaborative conceptual-conflict group exercises. In the other section [control group] we introduced only a summary writing activity. At one institution, classes were relatively small \( n = 32 \) students and at the other relatively large \( n = 100 \) students. Courses at the different institutions used different textbooks and had different formats. Outcome variables measured included student interviews and writing products. Both the interviews and the students’ writing products indicated that students in the experimental groups change their way of learning due to their exposure to the activities.

Keywords: science education, epistemology, inquiry, critical thinking

Introduction

A major problem for students entering postsecondary gateway science courses is that students can have great difficulty reading scientific texts and trying to cope with understanding the professor in the classroom. This is because in many gateway physics courses from the students perspective all that is required of the student is to understand and remember the meaning of some scientific vocabulary in the textbook and in lecture. However for the typical student the language and epistemology of science are actually akin to a foreign culture (Kalman, 2011). There is thus an analogy between such a student and an anthropologist spending time among a native group in some remote part of the globe. The student must record and decode the physics language and culture in the textbook and in the classroom.

A second major problem is that students who enter gateway science courses often do so with certain preconceived beliefs about the nature of science knowledge and learning (Donovan & Bransford, 2005). Moreover, most students have no notion that science could be learned more effectively in different ways other than how they have learned it in high school. Research reports that too often this is by memorization of information rather than a deep understanding of it.

Many students are not able to make a short-term transfer of principles garnered from a problem to the solution of an apparently different, but conceptually similar problem. Other students can dismiss the conceptual basis of the problems because their epistemology is formula-driven and they accept calculated answers as goals in themselves. Such beliefs are closely related to what philosophers would call a “student’s
personal epistemology”. However, as McCaskey (2009, p. 2) stated, “this is narrower in context than the strict philosophical definition (Steup, 2005), that is, of epistemology as encompassing the distinctions between knowledge, truth, and belief.” McCaskey went on to state that,

If a student believes that knowledge in physics should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is epistemological conflict. Likewise, if a student comes in thinking that physics consists of a bunch of equations to be memorized, and the instructor focuses more on concepts, there is conflict. Finally, if a student is being presented material in a fragmented way, but he or she would expect or believe the material should fit together more cohesively, that would cause another type of conflict. These conflicts (or, conversely, a lack of these conflicts) can affect learning above and beyond specific difficulties with mathematics or concepts. (McCaskey, 2009, pp. 2-3)

Students’ beliefs about the nature of knowledge and knowledge acquisition, namely, epistemic beliefs, have been demonstrated to affect their attitudes about science and science-learning processes (Baumert et al., 2000; Edmondson & Novak, 1993; Lising & Elby, 2005; Songer & Linn, 1991; Tsai, 1999; Urhahne & Hopf, 2004). Furthermore, nonscientific modes of thinking developed by many undergraduates have a negative effect on their interest and motivation (Adams, Perkins, Dubson, Finkelstein, & Wieman, 2004; Deslauriers, Schelw, & Wieman, 2011), thus preventing many capable students from persevering with science and engineering careers (Seymour & Hewitt, 1997). Moreover, science-knowledge acquisition based mainly on memorization that has often worked for students in high school, where the emphasis may unfortunately have been largely on absorbing factual information, will fail them during more concept-oriented university gateway-science courses (Lazarsfeld, 2004).

It has been long established that closing the novice-expert gap is one of the most difficult tasks in science teaching (American Council on the Teaching of Foreign Languages, 2001; Discenna, 1998; Kohl & Finkelstein, 2007; Slotta, Chi, & Joram, 1995; Winter, Lemons, Bookman, & Hoese, 2001). Chi and her collaborators (Chi, Feltovich, & Glaser, 1981) and Chi, Slotta, & de Leeuw (1994) theorized that the reason why novice learners have difficulty grasping science concepts is that they tend to build explanations (mental models) based on surface features. Chi and collaborators asserted that the many underlying structural and process attributes required to understand scientific concepts are not consistent with the surface features that they generate. Slotta & Chi (1999) stated, “once an ontological commitment is made with respect to a concept, it is difficult for this to be undone”.

Many novice science learners view science as loosely connected pieces of information to be separately learned, in contrast to the web of meaningful interconnections perceived by science experts (diSessa, 1988; Hammer, 1989, 1994; McCaskey, 2009; Sandoval, 2005). Elby (2001) has suggested that a holistic mode is required for meaningful learning. Students do not conceive of science in terms of a coherent theoretical framework. The student’s paradigm, in the Kuhnian sense, is that the subject consists of solving problems using a tool kit of assorted practices. “The professor classifies the problems in terms of physics concepts, while the students classify them by situations” (Hewitt, 1995, p. 85). Most students have loosely organized course concepts in contrast to the web of interconnections perceived by their instructors. Huffman and Heller (1995), in a study of 750 university students in a calculus-based introductory physics, course showed that most students’ personal (alternative) scientific conceptions “are best characterized as loosely organized, ill-defined bits and pieces of knowledge that are dependent upon the specific circumstances in question” (p. 141). In a similar vein, Hammer (1989, 1994) showed that some students view physics as weakly connected pieces of information to be separately learned, whereas others view physics as a coherent web of ideas to be tied together.

The purpose of this study was to investigate if and how a set of specially developed activities can help students change their approach to learning physics. We attempt to bring students to recognize that mechanics can be viewed as a coherent framework. A coherent framework is a highly ordered knowledge structure that embraces concepts, methods of applying concepts to solve problems, etc. It contains a coherent set of interrelated big ideas. As students learn, they relate new material to the material that they feel they already understand and in the process assimilate the new material within the framework.

Kalman and Aulls (2003) pointed out that
most students entering a science gateway course do not conceive of the subject in terms of a coherent theoretical framework. . . . The idea of the course design is that students would at first view the frameworks almost in a theatrical sense as a view of a drama involving a conflict of actors; Aristotle, Galileo, Newton and others occurring a long time ago. . . . As participants passing through a series of interventions, the students become aware that the frameworks relate concepts from different parts of the course and learn to evaluate the two alternative frameworks. (p. 762)

Specifically, the first objective was to help students to recognize the importance of concepts in learning physics. The second objective was to help students modify their learning approach so that they situated concepts within a framework. The third goal was to enable the students to review all their concepts and ask how these concepts fit into the framework presented in the textbook and by their instructor.

To meet these objectives, we have developed a suite of activities, the Reflective Writing Tool (Kalman, Aulls, Rohar, & Godley 2008), the conceptual-conflict collaborative group exercises and the critique writing exercises (Kalman & Aulls, 2003; Kalman, Milner-Bolotin, & Antimirova (2009). The Reflective Writing Tool enhances students’ understanding of concepts found in their textbooks by getting students to approach text in the manner of a hermeneutical circle.

The hermeneutic approach starts by having students initiate a self-dialogue about each textual extract. Within the framework of such a dialogue, there exist two “horizons.” There is the horizon that contains everything that a student believes from the particular vantage point of encountering the textual extract. The second horizon encompasses the potential in the textual extract; the sense in which the words, in the textual extract, are related within the language game understood by the author of the textbook. ... The student approaches the textual extract with misconceptions about the material within the textual extract. The key quintessential experience occurs when the student is pulled up short by the textual extract. The student questions what is known within the entire horizon. “A horizon is not a rigid frontier, but something that moves with one and invites one to advance further” (Gadamer, 1975/1960, p. 217; Kalman, 2011).

The conceptual-conflict collaborative-group exercise deals with students’ “personal scientific concepts.” “Students will cling to their personal concepts if problems with their personal scientific conceptions do not occur. This is because these beliefs make sense in explaining observations they have made about the physical world, and having taken the effort to construct their private understanding, students will not easily relinquish their original viewpoints” (Kalman, 2010). This is indeed the reason for the failure of traditional conceptual change theory. To remedy this problem, this exercise was devised to help students develop their critical thinking skills. Students are introduced to the idea that there can be more than one equally logical way of looking at a phenomenon in a social-constructivist setting (Vygotsky, 1978).

The critique activity was introduced to promote critical examination of the alternatives produced in the collaborative group exercise. It is in essence an argumentative essay in which students have to put forward as many possible arguments in favor of all the conceptual viewpoints raised in class and then point out which viewpoint is correct from an experimental point of view. Each of these activities has been previously evaluated as stand-alone interventions (Kalman & Rohar, 2010). Kalman and Aulls (2003) reported moderate success in getting students “to change from a view that science is a matter of solving problems using an independent set of tools, classified according to problem type, to a view that a science subject consists of a web of interconnected concepts” (p. 762). In the current work, we have investigated the extent to which exposure to this full suite of activities changes the way students learn science.

**Method**

This work consists of two studies at two different institutions. At each institution students in two sections were taught by the same instructor. In each study, one section [experimental group] was exposed to all of the target activities; reflective writing, critique-writing activities, and collaborative conceptual-conflict group exercises. The other section [control group] was asked to perform only summary writing of textual material before coming to class. We offer a common assignment to control groups that is a common reading study skill used by most students and for which some research is available showing positive effects of summary writing on recall and understanding. (Radmacher & Latosi-Sawin, 1995).
At one institution, classes were relatively small (n = 32 students) and at the other relatively large (n = 100 students). Courses at the different institutions used different textbooks and had different formats. Because these course conditions are typical of each institution we are hesitant to treat them as part of the same study in terms of the generalizability of results. However at both institutions students were randomly assigned to two sections by the registrar’s office.

Rubrics were designed to examine the reflective writing and the critiques. Rubrics were also designed to examine the interviews, which were later subjected to qualitative analysis. By combining quantitative test and rating results with semi-structured interviews about the same phenomenon, we treat the research design as a mixed-methods design combining quantitative data from the rubrics with qualitative data on the interviews to elaborate on the rubric outcomes and test the validity of the quantitative results. The interviews probed students’ epistemic beliefs and their views about and the nature of science, whether their views have changed, and, if so, the students were asked what brought about these changes. The interviews questions were developed over a one-year period beginning with a meeting of the whole research group. We started with interview questions that we had used in previous research and carefully honed the questions. These interviews were audio- or videotaped and transcribed.

Based on the preliminary data, the rubrics for analyzing the students’ writing products and interviews were designed using a mix of grounded theory and a priori codes, based on our previous research. Several versions of the rubrics were analyzed by the research team and applied to the writing products over an extended period until a final version emerged. The rubric for reflective writing includes eight categories reflecting increasing levels of competence, and the rubric for the critique includes four categories also reflecting increasing levels of competence. The interview rubric identified eight categories. Additionally, the first interview category included four subcategories and the second into two subcategories. These categories range from barriers and facilitators, to student learning, to changes in student learning strategies.

During the winter term of 2011 we had two sections of approximately 100 students in each section in a calculus-based mechanics course at a comprehensive university (institution A). We also had two sections of approximately 35 students in each section taking an algebra-based combination mechanics and electricity and magnetism course at a university-level community college (institution B). At each institution, in one section (the experimental group) students were exposed to all of the activities and in the other (the control group) students were asked only to perform summary writing of textual material before coming to class.

**Data and findings**

We evaluated the three activities in different ways but attempted to interpret patterns arising from the students responses to each activity.

*Reflective Writing Activity.* We evaluated 11 reflective writing products.

The following excerpt is from a student’s reflective writing sample [institution B] on Chapter 8 of Wilson, Buffa, and Lou, 2009

The theoretical content of this chapter is not all that different from chapter seven and fairly straightforward. It is more of a merging of the concepts of energy with more familiar problem solving strategies ... To me, a deceleration caused by kinetic friction of, say, 10 m/s² would produce an enormous amount of heat. I have never thought about where that energy goes till now. My first reaction was that the tire would not be able to handle that amount of energy transfer, which I now know must be false . . . What I still do not understand is if the capacity of brake pads to absorb heat is higher than I expected, or rather if the rate at which deceleration translates to heat is much lower (student LRch8-SC).

Eight raters from our research group examined the writing products with up to four raters for each individual product. Ratings were on a scale of 0, 1, 2, or 3 points in each category. In almost all categories there was close agreement in the ratings. For the two students from institution A with repeated work, we noticed an improvement in students’ competence over time in the fluency of the writing in the students’ own words, in their ability to identify that some ideas, facts, or data presented in the textbook were in conflict.
with the students’ own ideas, and then also to discusses the conflict. There was also an improvement in formulating and addressing their own questions. Overall, those students doing reflective writing had an average rating of 2.2 in identifying important concepts and 1.8 relating them to previously studied concepts within the course and 1.6 in relating concepts to their own life experiences. In the control group where students only did summary writing, the students an average rating of 1.3 in the ability to identify concepts, 0.5 in relating these concepts to previously studied concepts within the course and 0.7 in relating concepts to their own life experiences. All of the students performing reflective writing showed some ability to identify that some ideas, facts, or data presented in the textbook were in conflict with the students’ own ideas (average = 1.2) and some were able to discuss the conflict (average = 0.8). Most of the students performing reflective writing were able to formulate questions (average = 1.3) and some of the students addressed a question (average = 1.1). None of the students doing only summary writing noted conflicts with their own ideas.

Critiques. For the critiques, students were presented with two scenarios drawn from an earlier conceptual-conflict collaborative-group activity. One scenario corresponded to an explanation that does not have experimental validity and the other to the Galileo-Newtonian framework. Both scenarios had been presented by students in the classroom. Eight raters from our research group examined twelve critiques from the winter 2011 data with three raters addressing each individual product. Nine of these were from six students at institution A. The remaining three critiques were from three students at institution B. Ratings were on a scale of 0 to 3 points in each category. All the critiques were scored at least 2 in the category of identifying a key assumption or concept for every given viewpoint or scenario. All but one student scored at least 2 in the category of justifying (defending) the point-of-view of their choice. One student scored 1 on the first critique, but improved to a 2 in the second one. Only two students scored less than 2 in the category of justifying or defending the Newtonian point-of-view suggested in the assignment. Only three students scored less than 2 in the category of evaluating arguments of other students whose viewpoints were different from the one chosen by the student. One student had scored 3 in the first critique and decreased to 1.5 in the second. One student had scored 1.5 on the first critique and decreased to 0 on the second. One student had scored 1 in the first critique and increased to 2 in the second. One of the students in institution B also had a score of 1 in this category. Overall, seven of the 12 critiques received a total score of at least 10 of the 12 possible points.

During the post-interview students were asked what they had done at the beginning, middle, and end of the course to learn physics. Students who had done summary writing reported that that they were doing the same activities at all three times; typically reading the textbook, summary writing, and attending the tutorial session. In the reflective writing group a typical student reported that at the beginning of the course he was looking for direct examples of how to solve a particular problem, and by the middle of the course he was trying to think of the points he needed to take out of the chapters and write notes about them. More details emerged to support the idea that students had actually changed their ways of learning. One student stated: “I don't know if I'm older or anything but now I don't just want to copy and paste equations but to actually understand.” He was now more systematic: “Not just memorizing it; actually understanding. To actually apply it and to know how it actually works.” Another said “I kind of noticed that I am being forced to maybe change the way I think about things, that’s kind of helping, I am not good at it, but I, it’s interesting to sometimes catch myself at home thinking about some of the concepts we are taught for problem solving and then trying to apply it to situations.” Specifically he noted that, “in the middle I realized I needed to go over the chapters and take notes. I didn’t just write down equations. I tried to think of the points I needed to take out of the chapters and I’ll write the notes about them.” “The course has developed new ideas and ways of seeing things.” Reflective writing “forces you to think about what you are learning; helps in preparation; helps maybe clarify concepts.” And, about the group activity, “Yeah, good; it did mean there was reflection; try to think of how to say why that view was wrong or disprove that.” Another student noted that he “likes the conceptual group activity more than lectures.” “Sometime you think you’re right but then listening to others’ views you can learn about others as well; I cannot understand the question and my partner can so they can teach me.” As for the critique, “Without argument, how is one to know that the real view is the real view; important to disprove certain ideas.”
Discussion and Conclusions

The quantitative analyses entailed students who were randomly assigned by the registrar’s office to the two sections at each institution. At institution A, the number of students were large enough that it was unlikely that there was any difference between the sections.

At institution B, the numbers were small, and there could be a difference. At that institution, we had the students write the enhanced version of the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992). as a pre-test. Students in the experimental group had lower scores than those in the control group. Knowing this, we decided to compare the final examination scores in the two sections. We had not originally intended to compare the final examination scores because the exam was almost entirely problem-solving, though in a few short-answer questions some brief explanations were required. There were no essay questions.

A General Linear Model (GLM) regression analysis was performed on the data. We found that the experimental teaching method had a significant positive impact on students’ final examination scores. The independent variables (pretest FCI and teaching intervention) explained about 36% of the Final Exam variance. Since the FCI had not been run in institution A, we could not do this analysis in institution A. Although traditional problem-solving was not specifically targeted by the course activities, it was improved as a result of the suite of interventions given to the experimental group at institution B. Because the students in the experimental group had come to think of the course in terms of a framework, they most likely had developed a paradigm approach to solving problems. This would explain their higher achievements on the end-of-course examination.

Qualitative Results. Students in the experimental section had thought about concepts and related the concepts in a chapter to previous chapters and their life experiences. In chapter nine of his book to help science and engineering professors enhance their teaching, Kalman (2006) presented a letter from a student, who ended up getting a perfect score on her final examination:

In the first couple of assignments, I spent hours trying to figure out how to do the problems and never seemed to get the right answers. I didn’t understand why. During the classes, I followed along and seemed to grasp all of the concepts, and then when I got home, I couldn’t do the problems

After the midterm, I started to realize that the concepts were extremely important. . . . If there was a problem I couldn’t get I went through the concepts in order to try and understand what the problem was asking. And for the most part, even if I couldn’t get the right answer, I had the concepts and knew at least the gist of the problem.

Numerous studies have shown that many students, just like the student referred to above, have difficulty abstracting a principle from examples, encoding information into flexible memory representations, and accessing the appropriate principle in new problem contexts (VanderSoep & Seifert, 1994). For a novice problem solver, each problem on an exam is expected to correspond to a template. The student anticipates needing only change the information on the template to make it correspond to the exam problem. Such students lack the ability to apply principles garnered from a problem to an apparently different problem (Gick & Holyoak, 1980, 1983). To meet this challenge, students must make a shift in their learning from template solving (what Salomon and Perkins, 1989 call “Low-Road Transfer”) to solution by paradigms (what Salomon and Perkins call “High-Road Transfer”)—procedures to apply principles abstracted from many sample problems. Experts use paradigms—procedures to apply principles abstracted from many sample problems.

Looking at our third objective first: to enable students to review all their concepts and ask how they fit into the framework presented in the textbook and by their instructor, the rubrics showed that students in the experimental group were able to identify concepts and relate them to previously studied concepts within the course and to their own life experiences. They came to the realization that some ideas/facts/data presented in the textbook are in conflict with the students’ own ideas and then also to discuss the conflict. Students in the control group did not do this.
Looking at our second objective: We attempt to bring students to recognize that mechanics can be viewed as a coherent framework, we attempted to help students recognize that mechanics can be viewed as a coherent framework. As students learned, they related new material to that which they believed they already understood and, in the process, assimilated the new material within the framework. In doing the critiques, faced with scenarios taken from two different frameworks, all but one of the students were able to justify the point-of-view of their framework. In seven of the 12 critiques, the student writing the critique was also able to evaluate arguments based upon a framework that was different from the one chosen by the student. In three quarters of the critiques, the student could justify the Newtonian point of view suggested in the assignment. These outcomes indicate that most of the students in the experimental group had come to place the science presented in the course in the context of a Newtonian framework.

Looking at the first objective: to help students to recognize the importance of concepts in learning physics; student LRch8-SC had noted It is more of a merging of the concepts of energy with more familiar problem solving strategies. In the interviews, students typically stated thinking about some of the concepts we are taught for problem solving. Students in the experimental group had reported that at the beginning of the course, they searched the textbook for templates to solve problems. As the course progressed, students came to realize that solving problems requires an understanding of concepts.

The overall goal of the study was to investigate if and how a set of specially developed activities can help students change their approach to learning physics. The “how” was addressed in the three specific objectives. The “if” was also supported. Both the interviews and the student writing products indicated that students who were part of the experimental groups had undergone a shift in their thinking about physics and physics learning. No such indications occurred in the interviews and the student-writing products from students who were part of the control groups. Students in the experimental groups did change their way of thinking about science and the nature of science. Moreover, the way they approached studying physics indicated that the students changed their manner of learning due to their exposure to these activities. Furthermore, as a consequence of meeting these objectives, in institution B, the experimental group achieved higher scores on the final examination than the control group.

References


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STEM Education International: The ESTABLISH Project

Stephan Domschke and Martin Lindner, Dep. of Biology Education, Martin-Luther-University Halle-Wittenberg, Germany

stephan.domschke@biodidaktik.uni-halle.de, martin.lindner@biodidaktik.uni-halle.de

Abstract

The paper presents an overview of the various activities carried out under the patronage of the EU-FP7-Program ESTABLISH. The program doesn’t consider the various stakeholders of Science education as organised not in a hierarchie, but in collaborative settings. The paper contains the description of research design and results on various parts of this community: 1. The consortium constructing the teachin units, 2. Teacher students’ acceptance of STEM, 3. Science holiday camp, 4. An implementation at a school, 5. One example of a collaboration between a company and a school. All these examples give insight in the strategies, help to judge wether the approach functions and show the limitations of this program as well.

Keywords: STEM-Education, IBSE, International Consortium, EU-Project ESTABLISH, Collaboration School-Companies, recruitment in STEM, acceptance of STEM, implementation of IBSE and STEM education

STEM Education International: the ESTABLISH project

1. Introduction

In 2010, fourteen ESTABLISH - partners from eleven European countries started cooperation in linking Companies, Engineering, Schools, and Home (ESTABLISH) for progressive science education. The project is aiming at the development and the testing of teaching and learning IBSE - units, that are related to scientific and industrial problems. Such units will include appropriate support for both, in-service and pre-service teachers for the implementation of IBSE. The project is coordinated by Dublin City University. From here the key communities in second level science education are guided to cooperate in creating authentic learning environments in order to enhance a change in classroom practice.

These communities include:

(1) science teachers and educators, including science teachers’ networks;
(2) the scientific community, both, local enterprises and multinational industry as well as the scientific and industrial communities;
(3) the students of science in second level schools;
(4) the parents of these students;
(5) the policy makers responsible for science education at second level, including curriculum developers and assessment agencies and
(6) science education researchers.

This paper presents an overview of the various activities of the program dealing with a range of stakeholders involved in STEM education. It contains reports on the development of IBSE units by the consortium (Chapter 2), teacher students’ acceptance of STEM (Chapter 3), raising interest in science by participating in science camps (Chapter 4), implementation of IBSE in schools (Chapter 5), collaborations between schools and companies (Chapter 6). We would like to present the whole range of activities to show the broad field of work done by ESTABLISH.

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2. Development of IBSE - Units

The project consortium have adopted an agreed definition of inquiry as the “intentional process of diagnosing problems, critizising experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments” (Linn et al. 2004). Based on this definition extended group discussions have led to an identification of individual elements of inquiry. Teaching and learning units have been developed by the consortium to be used in teachers’ education – serving both groups, pre-service and in-service teachers—that are good examples of IBSE. The consortium has developed an agreed framework for the development of an IBSE – unit, that requires the developers to describe:

(1) Unit/science topic,
(2) IBSE character,
(3) Pedagogical Content Knowledge,
(4) Industrial Content Knowledge,
(5) Learning Path(s) and
(6) Student Learning Activities and Classroom Materials.

The learning path(s) can be organized by an instructional learning model. The learning cycle is one of the most familiar and effective models for science instructions. Exemplary learning activities included in ESTABLISH - units offer activities with reference to the stages of the 5E model of learning cycles based on a design study of BSCS (www.bscs.org). The five stages are Engagement, Exploration, Explanation, Expansion and Evaluation.

Using the framework, central IBSE - units are developed out of contributions from several project participants and through piloting in each country by the consortium members working with teachers. The central unit is then adapted for implementation in each country, taking into account cultural and curriculum differences. The criteria for each ESTABLISH - unit is that they conform to the ESTABLISH definition of Inquiry Based Science Education (IBSE) and encourage students to be active learners. The units must be representative of IBSE and inspire teachers to generate their own IBSE materials. These units should be connected to real world/industrial applications. Specific attention should be given to gender issues, ensuring that all materials are suitable for both genders. The topics of the first units are: Disability (focus on Biology), Invisible holes (Chemistry) and Sound (Physics). The second cycle includes the topics: Heating & Cooling; Chitosan; Electricity & Electronic components; Cosmetics & Blood donation, the third cycle will focus on: Photochemistry/Light; Renewable Energies; Surfactants; Light; Chemistry for Life; Polymers; Forensic Science; Medical Imaging & the Process of Science. These topics show the broad approach towards the aim of the project.

After three exemplary units had been created in 2011, these were tested at different levels (students – teacher students at university - in-service-teachers) nationally and internationally. The results show a great consensus of the teachers and of the consortium on the attraction for students as well as a great acceptance among in-service and pre-service teachers.

The results were gained by questionnaires and were evaluated on national and international level. They show, e.g., a greater acceptance of Biology-orientated content in comparison with technical / Physics content, a result we were already familiar with from various previous studies on interest in science subjects. However, the embedded presentation of such content seems to create a high acceptance even of these topics.

3. Teacher students’ acceptance of STEM

STEM teaching and learning is a new experience not only for the learners, but needs a change of the teachers’ attitudes as well. How do future teachers of Science and Maths accept STEM as a challenge? This is the leading question in the master thesis of Georges (2012).
At the beginning of the study we had to find a definition for STEM. It is not yet defined clearly, but comprises a combination of various facettes of modern Science teaching. It combines not only modern forms of classroom work, but also the basic scientific thinking and working methods of the Natural Sciences as well as Mathematics. This makes STEM a construct of high complexity, going much further than a simple aggregation of Science subjects. Thus STEM is a big challenge for those teaching and learning it. It can be characterized as a best-practise approach.

We tried to measure the level of acceptance among university students as well as among pupils at school (see below). What do teacher students, as the prospected STEM-teachers, think about STEM, IBSE and the embedding of Physics and Engineering into their Science classes?

Georges tried to answer these questions by a questionnaire survey with 120 teacher students (Georges, 2012). He tried to find out not only a positive acceptance towards STEM, but also the willingness to teach STEM in future classroom practise. Additionally he searched for factors that foster a positive attitude towards STEM teaching. In order to find an appropriate definition of “acceptance” he studied sociological papers, finding Lucke (1998) as a source for his defininition as follows: “Acceptance is a positive attitude towards STEM-Teaching, which does not only include agreement but also a readiness to act and a willingness to implement STEM”.

**Methods**

Georges used a paper-pen questionnaire with teacher students of Biology, Chemistry, Physics and Mathematics. He raised 62 likker-scaled items on beliefs, motivation and acceptance of STEM. The items are based on the item-definition of Riese (2009), Abd-El-Khalick, et al. (2002) and on Neuhaus et Vogt (2005). The acceptance scale was newly created, based on the given definition. 123 teacher students took part in the survey, 58 of them female. The numbers of students per subject were the following: Physics 41, Biology 35, Mathematics 34, Chemistry 13. Three students are studying two of these subjects.

**Data and findings**

More than 80% of the answers are above the average of 3, clearly indicating the acceptance of STEM. 14% of the answers show undecided opinions on STEM and only 6% are against STEM. As the numbers of these subpopulations are quite small, it was not possible to calculate statistical significance. According to this Georges was not able to define any correspondence between these results and gender or the subjects.

**Discussion and conclusions**

The great positive reaction to STEM might be due to the limited knowledge teacher students have of everyday classroom work. They might be too open for new ideas and might not be aware of the difficulties that are to be managed when it comes to real classroom practise. Research showed that young teachers return to copying the attitude and methods of their own teachers very fast when they have actually started teaching every day. This phenomenon is known as „Praxisschock“ (The transition shock in beginning teachers, e.g. Messner/Reusser 2000) and is one of the reasons for the still ongoing classic form of Science teaching, which hinders the implementation of STEM.

Georges could find hints to problems with STEM-acceptance by calculating the combination of factors. The following aspects are shown among students more reluctant towards STEM:
Students of Mathematics, Physics or Chemistry
Tendency towards fostering elaborated learning strategies
High subject and cognitive skills
High subject based self efficacy
Tendency towards fostering traditional learning strategies
Smaller focus on social interaction in the classroom
Less acknowledgment of everyday context in Science teaching
Less interest in testing new teaching/learning methods
After all, the results show the strong position we have to be aware of already with teacher students. It should be our duty to tackle these difficulties in order to foster STEM teaching and learning.

4. Raising interest in science by participating in science camps

Methods
The ESTABLISH – unit “Renewable Energy” is based on a workshop of a science summer camp. At this science camp pupils of various ages from different types of schools work on several scientific questions and hypotheses that they develop themselves. Starting from there they run inquiry projects that are designed along practical tasks which are combined with data gathered from the experiments and calculated on that basis to get an impression and an idea of the particular matter.

Meinl (2012) considers how learning in an open inquiry setting influences pupils’ interest in Science. In her Pre-Post-Follow up study (T1-T2-T3) she uses paper pen questionnaires with Lickert - scaled items that are based on the studies of Engeln (2004) and Pawek (2009). During and after the science camp she measured variables related to personal attitudes (specific or professional interest and self competence concept), perceived intrinsic variables of summer camps (emotional components, values, epistemic components, intended and expressed acts of interest).

Data and findings
In 2011 43 pupils (22 male, 21 female) aged15 to 16 took part in the summer science camp. Almost 90% of them said they wanted to repeat such a science camp in the next year. The number increased between the post- and follow-up-test. 70% of the participants reported a change of their attitude towards the science contents after joining the camp.

Concerning the individual development of interest, the science camp triggered joy (emotional component) in almost all participants and was seen as a personally important event (value based component) by nearly all participants. It helps developing the dispositional interest of most of the students by generating a long-lasting situational interest. A detailed analysis of parts of the group showed that the situational interest is developed independently from the self-concept of abilities. This shows an influence of the Science camp not only on those, who were already interested in Science, but also on the more generally interested students.

However, a difference could be measured in long-term habits. The students with a higher self-concept tend to be more engaged with continuing dealing with scientific problems than those with a lower self-concept. The latter intend to deal with Science, but in fact they are not as active as the other group. Their expressed acts of interest are rare in comparison to the first group.

Another positive result is the raise of interest in a scientific or technical career. Nearly 50% could imagine such a career after the camp.
Figure 1. Answers of participants of a science camp to the question: „Could you imagine to start a career in science and technology jobs?” (n T2:39, n T3:33), rated in % of the sample

- -- strongly disagree
- - disagree
- + indifferent
+ + agree
++ strongly agree

Discussion and conclusions

The results clearly indicate the effectivity of such Science camps. The setting is very effective in involving students into scientific and technological questions, because of the relaxed schedule, the experience to be part of a team, the opportunity to be involved in an intense problem-solving process lasting over a few days. The contact to real technology companies like an airplane wharf helps linking the more abstract contents to concrete contexts. All in all the ESTABLISH approach is fostered in an ideal way by such holiday camps.

5. Implementation of IBSE at school

To drive change in classroom the ESTABLISH consortium agreed to conduct pre-service and in-service teacher workshops facilitating the IBSE approach and the use of the materials developed. As a result of piloting the unit „Disability“ at a school a project for implementation of IBSE at this school, that follows the 5E model of BSCS, was developed.

Engagement phase

The engagement phase started with the piloting of the ESTABLISH unit “Disability”. Two biology teachers have been enthusiastic about the inquiry approach and wanted to implement IBSE and STEM education at their school. A benefiting aspect was also, that both teachers have been influenced positively by many teacher trainings before. So they were open minded on new learning and teaching approaches.

Exploration and Explanation phase

The teachers contacted the department of Biology education and asked for support, as the new headmaster of the school wanted to improve STEM teaching. He wanted to create a new subject for pupils in 9th grade who are more interested in natural science than in languages. We offered an introduction to the ESTABLISH program and the inquiry learning models.
**Elaboration and Extension phase**

After the introduction the teachers decided to run the implementation of IBSE and STEM education as their own project. They established a project team and elaborated the steps of implementation. After school-intern teacher trainings teachers of Mathematics, Physics, Chemistry, Biology, Geography and Computer Sciences started involvement and the work group extended. The school principal supported the work by providing an additional teacher for four hours per week promoting open learning methods in regular science classes. The first step of implementation was piloting the inquiry approach in the already existing Physics project. As the next step the project team planned a project for the last two weeks before the summer holidays in 2012. We supported them with teacher students who conducted the ESTABLISH - unit “Renewable Energy” in an 8th class. The school administration supported the project by a free disposal of the Mathematics, Chemistry, Biology and Physics lessons, at least 22 hours, and offering an extra room during the project phase.

**Evaluation phase**

The project team, the principal and the university students of our university evaluated the project. Their criteria have been acceptance, motivational aspects, change of interest and classroom management aspects. All stakeholders got a positive impression of IBSE and STEM education and decided to approach next steps of implementation that had to be elaborated.

The next step of the work group will be the implementation of the new optional subject “STEM” with two teachers for two hours per week in grade 9 since the beginning of the new school year. This subject is entirely inquiry-based science education. The implementation of more inquiry based classroom projects in grade 8 is planned for the near future.

6. **Collaboration between schools and companies**

As ESTABLISH has a special view on the collaboration of stakeholders, one focus of our research lies on the collaboration between schools and companies. It is not yet experienced very much, how to organize such collaboration and keep it sustainable, as several approaches to establish such collaboration lasted only for a few years.

**Methods**

Master students of our department observed collaboration between schools and companies in several cities of Germany and in Finland. They visit the schools, join activities between school and companies, interview teacher, students and persons from the companies and collect data via questionnaires. The combination of these methods helps to form a picture of typical factors fostering collaboration and make them fruitful for both sides.

In addition to this we are in contact with national associations fostering the exchange between schools and companies. These associations are mainly located in Southwest Germany, as the center of industry and commerce is centered there. The associations are semi-public, like chambers of commerce, or associations primarily for the public’s benefit. The members of these associations are delegates from companies and from research institutes. The activities have a broad range from supporting schools, financing labs or excursions or offering personal to bring information to schools.

**Data and findings**

Up to now we have only data from one collaboration: Nokia and its Paivola School in Finland. The research was focused on the motivation of the students. All indicators show an agreement to the motivation factors of Deci and Ryan (1985). One of the clearest answers are shown in Figure 2.
Besides this, all students report a feeling of great satisfaction on the topics they work on, as these topics are directly related to questions the company has. The questions are not “artificial” and the solutions the students generate are directly used for construction or production. The authenticity of such problems was seen as a great reward – both for the students as well as for the company.

Further observations on the collaboration between schools and companies often show a mismatch in the expectations both partners have. Companies tend to be a bit “impatient” with schools, as they are able to order a special behavior or process. School reality however builds on common agreement which is subject to longer approval process and which constantly changes.

Discussion and conclusions

As we have data from one collaboration yet, but a lot of observations and reports from all over Germany, we see the most rewarding effect for schools in the chance to see the “real world” by visiting companies, interviewing technicians and scientists or joining production processes.

7. Overall discussion and conclusion

The results presented show a positive development towards the ESTABLISH goals in the various activities related to the project. At this stage of the project the fostering, but also the hindering factors could be identified in a first shape. The overall result is seen in the fact, that a lot of parts of STEM Education are already working and are able to be brought into practice, but an overall picture is not yet developed.

The research on different levels of actors show the following results: on student (pupils’) level any change in “regular” classroom arrangement has a positive effect on motivation of the learners. In case teachers have a team at school to collaborate with, and in case the principal supports the implementation, STEM could be brought into practise quite fast.

Future teacher students show a broad acceptance of STEM, but it is to be doubted how much they will implement into their classroom work once they have started their work at school. Those who are reluctant have a strong subject orientation and feel more comfortable in traditional teaching approaches.

The implementation of STEM as a regular subject at a school was very much fostered by the school administration and the collaboration among a teachers’ team and among them and the university supporting the process.

Collaboration with companies remains a challenging area for schools. This results from the different culture of these bodies, but the examples we examined are carried out with great engagement and enthusiasm on both sides. Students feel well accepted when being guests at companies, companies show a dedicated good will to keep collaboration alive.

From an overall point of view the goals of ESTABLISH are on the one hand able to be reached. Several results of our research indicate positive tendencies. However, there is a lot work remaining, and the main challenge will be to scale the project’s approach up so that more teachers are able to profit from the results.
References


WCPE 2012, Istanbul, Turkey
“STELLA - School for Training in Experiments with Lasers and Laser Applications”: A Novel Approach to High-Level Education

M. Bondani, Istituto di Fotonica e Nanotecnologie – CNR, Como, Italy, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, and CNISM, Como, Italy
F. Favale, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, and CNISM, Como, Italy
O. Jedrkiewicz, Istituto di Fotonica e Nanotecnologie – CNR, Como, Italy, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, and CNISM, Como, Italy
F. Ferri, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, and CNISM, Como, Italy
P. Di Trapani, Dipartimento di Scienza e Alta Tecnologia – Università degli Studi dell’Insubria, and CNISM, Como, Italy

Abstract

STELLA School is an advanced education program in laser physics devoted to PhD and postdoctoral students in which highly qualified training in experimental techniques is delivered directly by expert researchers by using top-level research equipment. The basic idea of STELLA is the inherent unity between research and education, the same idea that seeded the birth of Universities in the Middle Age. To implement this approach, students and professors were involved in true research experiments that required the sharing of everyone’s skills and knowledge. STELLA School method has been evaluated through a short-term survey that investigates the opinions of the students about some core ideas of the School as well as their general satisfaction.

Keywords: Laser, experiments, high-level education

1. Introduction

The activities of “STELLA - School for Training in Experiments with Lasers and Laser Applications” took place in the laser-laboratories of the Department of Physics and Mathematics (now Department of Science and High Technology) of Insubria University at Como, Italy, from June 20 to July 9, 2011 (STELLA 2011). Similar events were previously hosted by the Laser Research Center in Vilnius (2007), the FORTH Institute of Electronic Structure and Lasers in Heraklion (2008) and the ICFO Institute for Photonic Sciences in Barcelona (2009) (VINO-STELLA 2009).

During three weeks of full immersion activities, several cutting-edge experiments in linear, nonlinear, classical and quantum optics have been staged directly in research laboratories, for training purposes. School participants were PhD students and Post-docs coming from all over the world.

The original aim of the School was to build a permanent European network capable of supporting the sharing of state-of-the-art technical know-how among the laboratories active in the field. The demand of such a joint effort in education follows from the increasing complexity of lasers, diagnostics, measurements and modeling techniques, which makes several small-size laboratories not adequate to cover the necessary training program for the young employed personnel.

STELLA School has proposed to the scientific community a highly innovative approach to training and research, which de-emphasizes competition among the laboratories in favour of true enhancement of knowledge levels. The action targets the establishment of long-term, stable synergy in training and research by creating a high-level technical know-how shared among the European young scientist community.

The driving idea behind STELLA is simple, being the same one that has seeded the birth of Universities in the Middle Ages: the inherent unity between research and education. The proposed concept of “School” stems from the experience that “a discovery begins when two or more people start sharing it.”
To this end, STELLA has challenged students, professors, assistants and local organizers to set up original experiments and computational works, thus tackling the achievement of genuine scientific results along with the realization of a didactic route.

Among the novelties of STELLA, we point out the last week of the course devoted to paper writing: students, professors and local organizers were jointly involved in writing a scientific paper on the results achieved during the School. The resulting papers were peer-reviewed and published in the volume 199 of The European Physical Journal Special Topics (Bondani 2011) that also contains the output of an evaluation questionnaire directed to students and professors aimed at a short-term project evaluation (Favale 2011).

2. Method

2.1 Project funding

STELLA School was funded by CARIPLO Foundation (318,5 KEuro) within a Call for the development of Human Capital (project number 2009-2964 “STELLA: A School for Training in Experiments with Lasers, Laser applications and gravitational physics”, May, 1 2010-October, 30 2012) and co-funded by University of Insubria (40 KEuro), Univercomo (10KEuro), the registration fees (25KEuro) and Fondazione Banca del Monte di Lombardia (40KEuro). Moreover a number of technical sponsors supported the experimental activities (Hamamatsu, Altechna, Light Conversion, Nikon, Amplitude Technologies, HighQ Laser).

The funds were used to cover the expenses for planning and mounting of the experiments, including the acquisition of new equipment when needed; mobility, board and lodging for professors and assistants, both during the preparation stage and during the period of the School; secretary and technical personnel; partial support for students.

2.2 Preparation

The preparation stage of the School activities took more than one year and involved directly the invited expert researchers and their collaborators together with four researchers of the Department and their assistants who made their laboratories available for the School. The preparation stage consisted in the detailed planning of the experiments, the mounting of the experimental apparatus, either at professors’ Institutions or directly in Como, and the final installation of the experiments in the laboratories few weeks
before the beginning of the School. The necessary equipment was provided partially by local organizers and partially by guest professors themselves. During this stage, all the invited professors came at least once to Como to plan the activities with the local organizers.

Finally, few months before the beginning of the School, professors were required to prepare a paper draft that was made available to the students on the School web site. The draft had the twofold utility of being a base for the preparation of the experiments and the structure of the scientific paper the students had to write during the third week of the School.

2.3 Participants
STELLA School enrolled 36 students, 11 professors, 16 assistants (internal and external). The students, who were requested to be at least graduated, were PhD students (22), PostDoc students (2), Master students (9), assistant professors (1) and researchers (2). With respect to the gender, the group was made up of 8 female and 28 male students.

STELLA students came from all over the world (North and South America, Europe, Asia, and Australia) and most of them (25) had never participated to any other high level physics school before.

2.4 School Program and students’ curricula
STELLA School offered 11 courses, consisting of 9 experimental activities and 2 numerical activities dealing with different aspects of laser optics research (see Fig. 2).

The action was organized during three weeks and was devised to provide each student with 120 hours of intensive training, organized in 8 hours of plenary sessions, a curriculum of two separate 32-hours technical courses and a 48-hours training in scientific writing.

Each student chose two courses among the 11 different courses offered by the School. The 9 experimental activities involved groups of 4 students, while 2 activities on numerical simulations where combined and involved a group of 8 students. Each course lasted four consecutive days in the first week of the school (Tuesday to Friday) and was repeated for a different group in the second week (Monday to Thursday).

Starting from Friday of the second week and during the entire third week of the School, the students had to write a number of papers on the attended activities to be submitted for publication in a peer-reviewed issue of an international scientific Journal. Each student chose one of the two attended courses. The writing work was supervised by the professors responsible for the courses together with local contacts. Students’ contribution to paper writing has been data analysis, presentation and interpretation of the results, final comments. All the papers underwent a peer-review process and were finally published in a monographic volume dedicated to STELLA School by European Physics Journal Special Topics (EPJ ST) (Bondani 2011).
The last paper of the EPJ ST Issue reported the results of a quantitative survey that was carried out during the last day of the School. The object of the survey was the evaluation of the students’ motivations to attend such a School, their achieved learning and their general satisfaction about the attended courses.

3. Results

The results obtained from a project like STELLA School can be analyzed on different time-scales. In the short-term period (immediately after the School), we can evaluate the perception of the participants about their own improvement in knowledge and skills and the success of the organization from the logistic point of view. In the medium-term period (one-two years) we can evaluate the formative success of the training of each student, the follow-up in the specific research field and the opening of new research lines connecting the groups involved in the School activities. Finally, in the long-term period we expect the success of STELLA School method to appear in the settling of a different approach to research based on collaboration instead of competition.

At the moment, we can only evaluate short-term and, partially, medium-term results, while for long-term results we will perform new monitoring activities in the following years.

3.1 Short-term results: evaluation of STELLA School by the participants

To implement a “short-term” evaluation of STELLA School method we designed and analyzed a quantitative assessment instrument consisting in a questionnaire made of 15 questions to be given to students to be completed the last day of the School. Of the 36 forms distributed to students and 32 were completed (response rate of 88.8%) A similar feedback form was also given to professors and assistants (11 surveys completed out of 19 distributed), which was used to compare the outputs of some questions (see below). We focused the questions of the evaluation questionnaire on the contents of the proposal, to understand if the participants could get the core message of STELLA (see Editorial of (Bondani 2011)). The complete analysis of the questionnaire is reported in (Favale 2011). Here we only summarize some of the main results.
First of all, we observe that the initial evaluation yielded a very good overall result, in that the experience has been largely appreciated by the totality of students who declared that they may suggest it to other colleagues and they would like to take part in other training programs like STELLA School in the future (see Fig. 3).

Second, the students completely entered into the spirit of the School, greatly appreciating the experimental hands-on character of the activities, the opportunity of collaborating and of sharing knowledge and skills. Moreover, students felt themselves involved in a “real” research task (see Table 1).

Among the weak points of the School, we find the activity of “paper writing” that arose some critical remarks by the students (see also Fig. 4) due to the tight schedule of the School program. At variance with students, professors judged this activity very positively. Indeed they highlighted the importance of concentrating the efforts of the students, guiding the research path and the laboratory activities towards publication that would enrich students’ curricula.

Nevertheless, both students and professors declared that they experienced a rather high level of pressure to accomplish paper writing in a relatively short time. Many students and professors observed that they would have preferred a different balancing between laboratory activities and paper writing, so as to have more time to perform both activities in a satisfactory way.

Actually writing a scientific paper is a difficult task even when the starting point is a paper draft, prepared in advance by school professors. For this reason we believe that the publication of the EPJ ST issue a few months after the School is a very important result.

Table 1. Answers to Questions 9. “What in particular do you think are the “strong points” of the STELLA School?” and 10. “And what do you think are the “weak points” of the STELLA School” (Favale 2011). The number of answers is on a total of 32.

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Figure 3. Answer to Questions 15. “Would you recommend a school like STELLA School to your friend/colleague” of the short-term evaluation questionnaire (Favale 2011). “na” means no answer.
3.2 Medium-term results

3.2.1 Training results

First of all we note that the students were invited to choose at least one of the two courses in a field different from their usual research topic in order to give them the possibility of extending their knowledge and skills in a much broader field and of participating to a research activity completely new for them.

The short-term evaluation questionnaire included some questions concerning the self-perceived personal improvement during the School (see Fig. 5) showing that the large majority of the students perceived an enhancement of their scientific “level” with respect to the initial background. We observe that it can be difficult for a student to judge his/her own acquired skills in the short period, before having had the opportunity of employing them in a different experimental situation. Therefore it would be more informative to repeat the question in long-term surveys.
Proceedings of The World Conference on Physics Education 2012

Figure 5. Answer to Questions 8. 8.1: My understanding in the field of Laser physics was improved. 8.2: My experimental/numerical laboratory skills were significantly improved. 8.3: My research capacity was improved. 8.4: I learned techniques directly applicable to my work. 8.5: The material presented in STELLA School was relevant to my research. 8.6: I felt myself involved in “real” research task. 8.7: I learned how to write scientific paper (Favale 2011).

3.2.2 Research results

The experimental activities performed during STELLA School yielded true scientific results. In fact, each course activity contained some novelty factor with respect to the state of art of the research in the field, either in the set-up or in the experimental results, which made them worth being published in a peer-reviewed scientific Journal.

The quality of the obtained results is the demonstration of the value of the proposed approach based on the unity between high level training and research.

New equipment and new technical skills were transferred to the local researchers and are now available in the laboratories of University of Insubria and some of the subjects investigated during the School have opened new research lines in research collaborations among STELLA School professors and local organizers (e.g. research activities on single molecule fluorescence fluctuation spectroscopy, nanofabrication of transparent materials, microscopy).

3.2.3 Follow up

Mobility of some students and professors from and to Como during the year following 2011 edition of STELLA School. In particular, some PhD students decided to return to Como to join for a period local research groups. Moreover, some STELLA students moved through the research groups participating to the School to continue the experiments or to join new research activities (e.g. from Milan and Como to Fribourg, from Vilnius and Olomouc to Como, from México D.F. to Pavia…).

STELLA School has achieved a notable international visibility as a model for high-level education. In fact the organizers have been contacted to take part to international projects, among which we mention in particular, two ITN Projects in which the University of Insubria will coordinate the setting up of future editions of STELLA School.
3.2.4 STELLA 2012 in Pavia

A new edition of STELLA School funded by the same CARIPLO project was held in Pavia from June 18 to June 29, 2012 (see the poster in Fig. 6) (STELLA 2012). Pavia local organizers decided to limit the School activities to two weeks and to five experiments without paper-writing session. The School participants consisted of 15 students from Europe, Asia and South America, 4 professors and 6 local organizers and assistants.

3.3 Long-term results

We will perform a new survey among the participants of STELLA School 2011 in order to calibrate the proposal for a new edition that we hope will be funded in 2014. For instance we could modify the organization of the activities to minimize stress and enhance the strong points of the School.

We will also monitor the development of all the new research lines that originate from STELLA.

4. Discussion and conclusions

STELLA School objectives were very ambitious: the goal was to demonstrate that the idea of unity between education and research, together with the emphasis on collaborative work instead of competition, could yield relevant results in both research and education. To reach this target, the organizers challenged professors and students to make a discovery and to write the results of the research in scientific publications within the School weeks.

We can say that the program succeeded, even if, in the organization phase, the main challenge was to find scientists ready to share their skills and to involve themselves completely with the students. Moreover, the limited time available for the experiments made the work hard and a little bit pressing. Finally, the third-week writing session was very demanding both for students and professors.

A possible solution for future editions of STELLA School is to offer each student a single training course instead of two, lasting three weeks (including paper writing). Of course, this solution reduces the possibility for students to experience research in fields different from the ones they are used to.
In conclusion, we can assess that STELLA School method has proven itself effective and has been appreciated by students and professors. Moreover, the creation of a human environment favorable to collaboration and knowledge sharing has brought all the experiments to positive results, in spite of all the differences in conduction, topic and complexity. One of the most surprising outputs of the School is the publication of the Issue of EPJ ST dedicated to STELLA.

Acknowledgements

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STELLA 2012 http://etf.unipv.it/stella
Testing Student Basic Concepts in Electricity

Hildegard Urban Woldron, University of Vienna, Austrian Educational Competence Centre Physics, Austria

Abstract

Often, profound misconceptions prevent students to get a firm grasp of basic concepts in electricity. Identifying and removing these blocking stones is the key to progress in physics education. Straightforward knowledge tests are generally not suitable to identify these misconceptions as students might arrive at the right answer in a test, but based on wrong assumptions. Although multiple-choice questions are widely used instruments for assessing student understanding, care is needed when interpreting students’ responses, as correct answers can be false indicators of student knowledge and understanding. Based on findings from physics education research the author aims to develop a valid and reliable diagnostic instrument, to quickly and efficiently detect students’ alternative comprehension concerning basic concepts of electricity. Additionally, there is a focus on figuring out specific relationships between different misconceptions and making the test instrument applicable both for physics education research and the teachers in the measure of students’ qualitative classrooms. The author presents here a questionnaire as a diagnostic tool to identify these misconceptions. Core to the tool are questions asking both for (1) expected outcomes in simple circuits with lamps and other resistance elements and (2) addressing also the underlying assumptions. The questionnaire was developed and refined in field tests in Austrian schools; data obtained have confirmed its suitability, robustness and precision in measuring such basic obstacles in physics education. Furthermore, some quantitative techniques such as confirmatory factor analysis and structuring equation modeling revealed that the test scores could be a valid and reliable instrument for testing understanding and the correlation according to different misconceptions.

Keywords: electricity concepts, valid and reliable diagnostic instrument, two-tier items, student misconceptions, resource for physics education research

1. Introduction

Electricity is one of the areas in physics most studied in terms of learning difficulties. Thereby, a significant part of these studies refers to the teaching of simple electric circuits highlighting three categories of student difficulties: inability to apply formal concepts to electric circuits, inability to use and interpret formal representations of an electric circuit, and inability to qualitatively argue about the behavior of an electric circuit (McDermott & Shaffer, 1992). Students may have various, often pre-conceived misconceptions about electricity, which stand in the way of learning. Some think that current is ‘used up’ by lamps in a circuit, as if electric current would be comparable to a liquid fuel taken up by a combustion engine. Some think that a battery is primarily a source of constant current, not of constant voltage. The effects and underlying root causes when connecting lamps in a circuit serially or parallel are not intuitively understood by most students. Such misconceptions are not new and have been researched in physics didactics for some time. Misconceptions are strongly held and stable cognitive structures, which differ from expert conception and affect how students understand scientific explanations (Hammer, 1996). In addition, Duit and von Rhöneck (1998) point out the relevance of students’ pre-instructional conceptions in the learning of physics. Therefore, there is need for diagnosis instrument to get informed about students’ preconceptions and also for evaluating the physics classroom.

In order to identify and measure students’ misconceptions about electricity different approaches have been made. Most of the early research related to students’ conceptions in basic electricity was done with more formal interviews (Osborne, 1983; Fredette & Lochhead, 1980; Fredette & Clement, 1981) or open-ended ones. McDermott and Shaffer (1992) used so-called ‘individual demonstration interviews’. Beichner (1994) combined interviews and multiple choice tests, Shipstone (1988) employed multiple choice and ‘true- false’ questions and Engelhardt and Beichner (2004) developed a multiple choice test, the so-called DIRECT (Determining and Interpreting Resistive Electric Circuit Concepts Test) to detect and interpret concepts about direct resistive circuits. The DIRECT instrument was used with hundreds of college and high school students and can help to evaluate curriculum or instructional materials and various teaching
approaches. Treagust (1988) introduced the two tier test method and Pesman and Eryılmaz (2010) used the three tier test methodology for developing the SECDT (Simple Electric Circuits Diagnostic Test). Each of the diagnostic tools mentioned above has some advantages as well as disadvantages over the others. On the one hand, interviews provide in-depth information about the students’ cognitive structures and reasoning. On the other hand, interviews can only be conducted on a limited number of individuals. In contrast, diagnostic multiple choice tests can be immediately scored and applied to a large number of subjects. As ordinary multiple choice tests with one-tier were highly criticized in overestimating the students’ right as well as wrong answers, two- and three-tier tests were developed by researchers. Starting from an ordinary multiple choice question in the first tier, students are asked about their reasoning in the second tier, and respectively, students estimate their confidence about their answers in the third-tier.

In view of lack of instruments for testing electricity concepts of students at grade 7 and for being suitable to the Austrian physics curriculum, the author aimed to develop a two-tier diagnostic instrument for assessing students’ conceptual understanding as well as its potential use in evaluating curricula and innovative approaches in physics education (Urban-Woldron & Hopf, 2012). Apart from looking at the outcomes and evaluation of electricity courses, the instrument should also be applicable to be used by teachers to informatively assess understanding of basic electricity for actuation of the teaching process. Related to content, the focus was on the understanding of electric current. As findings about conceptions of current reveal, many students adopt one or more conceptual models of electric current that are not compatible with the conservation of current. For example, students tend to assume that current is consumed and that the battery is a source of constant current rather than constant voltage. In addition, many students fail to develop a conceptual understanding about resistance and its role in a circuit. Furthermore, students seem to be unable to consider a circuit as a whole system, where any change in any of the elements affects the whole circuit. In consequence they demonstrate ‘local reasoning’ by only focusing their attention on one specific point in the circuit and by ignoring what is happening elsewhere in the circuit. Additionally, students show ‘sequential reasoning’, by which they believe that when any dynamic change takes place in a circuit, only elements coming after the specific point are affected.

Specifically, the following two research questions were raised:

1. Can a two-tier multiple choice test be developed that is reliable, valid, and uncovers certain students’ misconceptions?
2. Can a two-tier multiple choice test be developed to identify relationships between certain students’ difficulties linked to research based misconceptions?

1. Methods

In order to develop a reliable tool to identify students’ misconceptions and also their relationships, the author first conducted interviews based on literature review, both more structured ones and also with open-ended questions. In an initial stage a 45-item questionnaire was developed, including 11 two-tier items (meaning question plus follow-up question, an example is provided further below).

In first round of evaluation with 14 teachers and 43 students (grade 12, 28 f(emale), 15 m(ale)), the questionnaire was reduced to 30 items, still including the 11 two-tier items. After a test run with 422 students of grade 7 to grade 12 from from middle and high schools across Austria after formal instruction (225 f, 197m, mean age 15.1 y(ears), S(standard) D(eviation) 1.9 y) results were evaluated with the software programs SPSS, AMOS and WINSTEPS. In a polishing round, additional interviews were used to optimize the test items and especially the two-tier items. To get the score for a two-tier item, a value of ‘1’ was assigned when both responses were correct. Furthermore, by examining specific combinations of answers other relevant variables were calculated to address students’ misconceptions.

In the following, the author presents two two-tiered items, both asking questions related to very simple electric circuits; as we will see, there is ample space for misconceptions despite their simplicity. We need to add here that the provided answers have not been thought up by the researcher but are based both on literature review and actual experiences with students. Figure 1 shows an example for the first two-tiered item A. Item A has the item number 11 in the test.
Figure 1. Two-tiered item A: Brightness of 5 identical bulbs connected serially in a simple circuit.

<table>
<thead>
<tr>
<th>a) How bright will the bulbs be? (Hint: The five bulbs in this circuit are identical.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp L1 is lit. The others are off.</td>
</tr>
<tr>
<td>X All the lamps are lit with the same brightness.</td>
</tr>
<tr>
<td>Lamps L1 and L5 are brightest, and then lamps L2 and L4, and L3 is dimmest.</td>
</tr>
<tr>
<td>L3 is brightest, then L2 and L4. L1 and L5 are dimmest.</td>
</tr>
<tr>
<td>Lamp L1 is brightest, then they get gradually dimmer as you go round the circuit</td>
</tr>
</tbody>
</table>

b) How would you explain your reasoning?

| The first lamp uses up all of the electric current, so there is none left for the others. |
| Each lamp uses up some of the electric current, so there is less left for the next one along. |
| The electric current gets weaker as it gets further from the battery. |
| X The electric current is the same all around the circuit. |
| The electric current is shared between the five lamps (meaning each lamp uses up 1/5th of the current and leaves the residual current to the other lamps). |
| The electric currents from the two terminals of the battery meet at lamp L3. |

Obviously, the correct answers would be a2 and b4. We now have a look at several common misconceptions.

**Misconception #1 (Answers a2, b5)**

In this misconception the student chooses the right answer, but based on the erroneous assumption that each of the lamps “uses up” one fifth of the current and leaves the remaining current to the other lamps. Consequently, the current after the last lamp would be zero, as all of it had been used up by the five lamps. This is a prime example that a correct test answer is not yet proof that the student had really understood the underlying concept.

**Misconception #2 (Answers a3, b6)**

Here, a student selects a3, where the lamps closest to the battery (L1, L5) shine brightly and the one in the middle (L3) is the dimmest. L2 and L4 are between [L1, L5] and L3 with respect to brightness. At first, this answer seems to make no sense to a physicist, but the follow-up answer b6 sheds some light on the situation: the student thinks that currents leave the battery at both ends and are mostly used up when they meet at lamp L3. Basically, this is a creative variation to misconception (a2, b5), ‘current used up by the lamps’, discussed in the previous section.
Figure 2. Two-tiered item B: Replacing a resistor by one with a higher resistance and the effect on the magnitude of the electric current

The resistor in the circuit (figure on the left), $R_1$, has a small resistance. It is replaced by $R_2$, which has a large resistance (figure on the right).

**a) What happens to the current in the circuit?**

- It gets bigger.
- It gets less, but not zero.
- It stays the same.
- It drops to zero.

**b) How do you explain your reasoning?**

- The battery is not strong enough to push any current through a larger resistor.
- The battery cannot push as big a current through a larger resistor.
- A large resistance needs more current than a small resistance.
- It is the same battery, so it supplies the same current.

Also here, the correct answer is obvious: a2. But not every student who chooses it does it for the right reason. Item B has the item number 3 in the test.

**Misconception #3 (Answers a2, b3)**

Also the reasoning behind misconception #3 does not lack creativity. The student assumes that the higher resistance uses up more current than the lower resistance, and so, less current remains in the circuit.

**3. Data and Findings**

In order to make use of two-tiered items, detailed analysis was undertaken for each item. For example, as shown in figure 3, crosstab analysis highlights how widespread the misconception ‘current is used up’ is: In the pilot test run of the questionnaire with 422 students, 56% choose the right answer a2 to the question in the first-tier, but of all who did so, 40% then went on to select answer b3 in the second-tier. Only 54% of the students, who answered correctly in the first-tier (a2), chose also the right answer in the second tier (b2). 26% of the students assumed the battery to be a source of constant current and 15% thought that the current gets bigger, if a larger resistor is built in the circuit.

Supplementary, item B (see figure 2) was used to model also the following further two misconceptions: ‘a battery is a source of constant current (a3b4)’ and ‘the current gets bigger because a larger resistor needs more current (a1b3)’.
Figure 3. Results from a crosstab analysis for item B

Figure 4. shows more details concerning the appearance of the misconceptions mentioned above related to the person ability: Based on a total score of 30 points, 43% of the students, who could arrive at 15 points, chose the correct answer for both tiers. 37% of those students answered in a false-positive manner what means that they gave the correct answer for the first-tier accompanied by an incorrect explanation by assuming that current is used up. Furthermore, 15% of those students supposed the battery to be a source of constant current, and the remaining 5% thought that the current gets bigger because a large resistor needs more current than a small resistor.

For representing the reliability of the test, difficulty levels, which ranged from moderate (.57) to high (.11) as well as internal consistency, given by Cronbach alpha (.84), were used. Content validity was proved by presenting the test and objectives to expert teachers to ensure that the domain was adequately covered. Construct validity was evaluated through a factor analysis. By analysing the interrelationships within the data groups of items that appeared to measure to measure the same idea or factor could be selected. Confirmatory factor analysis with AMOS, using the maximum-likelihood-method and including specific combinations of answers due to the first and second-tier of five different test items, resulted in a χ²-value of 4.543, which was not significant (p = 0.337). Therefore, a latent variable ‘current is used up’ could be established (see figure 5). Similarly, nine further ‘misconceptions’ were emulated by applying factor analysis to define new variables. For example, ‘a battery is a source of constant current’ or ‘local reasoning instead of systemic reasoning’.

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Next, structural equation modeling using the software AMOS proved the relationships between distinct misconceptions of theoretical models in accordance with the empirical data. The model in figure 6 consists of six latent variables, two of them or exogenous and four of them are endogenous. There is no relationship between the two exogenous variables. The path coefficients displayed in figure 6 indicate positive values between the latent variable ‘current is used up’ and the two variables ‘current use up is proportional to resistance’ and ‘sequential argumentation’. Additionally, there is a moderate negative path coefficient from ‘a battery is a source of constant current’ to ‘sequential argumentation’. The highest path coefficient (0.64) indicates that students, who assume a battery as a source of constant current, tend to think that the resistance does not influence the amount of current.

Furthermore, also the results from Rasch-analysis were in accordance with the empirical data. Figure 7 displays the probabilities for three items dependent from person ability according to the empirical data of the sample described previously. As item 6 is the most difficult one (item difficulty index $d = 1.31$), the probability to solve this item correctly for a person with a personal ability $p = 1.45$ is about 53%. Otherwise, the same person will solve item 22 (item difficulty $d = -1.21$) with a probability of 92%.
4. Conclusions and discussion

The author has developed a questionnaire as a diagnostic tool to identify common misconceptions in electricity among grade 7 to grade 12 students (15.1 years old on average). As ten different alternative conceptions in the context of basic electricity were identified, the findings suggest that the conceptual understanding test is useful in diagnosing the nature of students’ misconceptions related to simple electric circuits and therefore, can serve as a valid and reliable measure of students’ qualitative understanding of simple electric circuits. Furthermore, some quantitative techniques such as confirmatory factor analysis and structuring equation modelling revealed that the test scores could be a valid and reliable understanding of the correlation according to different misconceptions. Therefore, the test instrument could be applicable both for physics education research and for the teachers in the measure of students’ qualitative classrooms.

The test allows the teacher to assess students’ understanding of basic electricity in more depth than with simple knowledge tests. For example, looking at figure 3 again, we can assume that not 56%, but only 30% have an appropriate understanding of the relationship between the resistance in a circuit and the current. In other words, if we do without the second-tier we definitely overestimate the correct answers and gain a wrong vision of student understanding. In conclusion the findings of the study indicate the following: first, two-tier items in a reliable and valid test instrument can uncover certain students’ misconceptions. Second, a two-tier multiple-choice test can help to identify relationships between certain students’ difficulties linked to research based misconceptions.

The questionnaire is available in German or English from the author.

Further research will focus on improvement of the test with three tier items for evaluating students’ confidence and also with a larger number of students. Additionally it is intended to introduce the instrument to teacher training courses and to use it for assessing new curriculum materials and/or teaching strategies.
References
Testing Students’ Conceptual Understanding in Geometrical Optics with a Two Tier Instrument

Claudia Haagen-Schuetzenhoefer, University of Vienna, AECC Physics
Martin Hopf, University of Vienna, AECC Physics

Abstract

Light phenomena are part of our everyday experience. Despite, or maybe because of these frequent and intensive encounters with light, it turns out to be difficult for students to transfer their everyday conceptions into scientifically adequate ones. Conventional instruction does often fail to consider research findings and is thus seldom successful in promoting lasting conceptual change. Currently, we are developing optic learning materials for lower secondary students which are based on physics educational research findings. In order to evaluate the learning processes triggered by these materials, an appropriate assessment tool is needed which is able to portray a student’s conceptual knowledge base. Existing test instruments meet our requirements only partly. So, our main research objective is the development of a two tier multiple choice test which is able to portray lower secondary students’ conceptions in geometrical optics. Our aim is to design the test instrument for two different application areas: Firstly, the test shall be used for physics education research. Secondly, the optics test shall support teachers in formative assessment of their students’ learning processes. Especially the second goal requires a test format which can be administered easily and quickly in school settings. As a result, we decided for a two tier multiple choice format. This paper presents the first steps of the development of this two tier optics test instrument.

1. Introduction

Light is an important part of everyday life. We daily encounter various different optical phenomena. Despite intensive experience with light, understanding geometrical optics turns out to be difficult for students. Physics education research of the last decades shows that students hold numerous conceptions about optics which differ from scientifically adequate concepts (Duit, 2009). These alternative conceptions turn out to be extremely persistent. Efforts to transform them through regular instruction into scientifically accepted ideas have proven to be only partly successful (Andersson & Kärrqvist, 1983; Fetherstonhaugh & Treagust, 1992; Gallili, 1996; Langley, Ronen, & Eylon, 1997). During the 1990 Wiesner et al. designed a research based course which can be named as one example for an intervention that turned out to be efficient for most key ideas of geometrical optics (Herdt, 1990; Wiesner, Engelhardt, & Herdt D., 1995).

A research project on geometrical optics is carried out at the AECCP at the University of Vienna at the moment. One goal of the project is to design learning materials on the topic of geometrical optics for year 8 students. The materials are based on the content structure of the course developed by Wiesner et al. (Wiesner et al., 1995; Wiesner, Engelhardt, & Herdt D., 1996), which was published in form of a teachers’ book only and not as a students’ text. In order to evaluate the learning output caused by these student materials an instrument to measure students’ conceptions on geometrical optics pre and post the intervention is needed.

Research on alternative conceptions in optics has mainly used the methods of interviews or questionnaires with open answers (Andersson & Kärrqvist, 1983; Driver, Guesne, & Tiberghien, 1985; Guesne, 1985; Jung, 1981; Viennot, 2003). In addition to these quite time consuming methods of investigation, some multiple choice tests were developed (Bardar, Prather, Brecher, & Slater, 2006; Chen, Lin, & Lin, 2002; Chu, Treagust, & Chandrasegaran, 2009; Fetherstonhaugh & Treagust, 1992). These tests focus on various age-groups and on different content areas within geometrical optics. We have, however, not found a psychometrically valid test instrument designed to portray basic conceptions in geometrical optics of students on the lower secondary level. These circumstances made it necessary to design a test instrument suiting our purposes.

Our main research objective is the development of a multiple choice test instrument which is able to portray lower secondary students’ conceptions in geometrical optics. Our goal is to tailor such a test for
two different purposes. On the one hand, the test shall be used for research e.g. to evaluate students’ conceptual learning. On the other hand, the optics test shall be designed for teachers to assess their students’ learning processes.

2. Methods

Choice of the Test Format

In order to evaluate the effectiveness of instruction which was designed to promote conceptual change in students, appropriate assessment tools are necessary. This is not only true for research purposes as described above, but also essential for teachers to gain feedback on student learning (McTighe, 2011).

When dealing with students’ assessment two main aims may be distinguished: The first aim can be summarized as making judgements about students’ performance, so to say to assess if students know certain scientific facts. This way of assessment is rather output oriented and does not focus so much on the quality of concepts held by students.

A second aim of assessment is to explore students’ (pre)instructional conceptual knowledge base. This kind of assessment is mainly to portray students’ conceptual knowledge base and changes within this base triggered by instruction. Feedback from this kind of assessment can be used for several purposes. It can support students in their individual learning process by recognising their potentials for improvement. On the teacher level, it can function as basis for further teaching decisions since such test results represent the effectiveness of classroom instruction and it may help to detect learning problems in a certain area of learning. Finally, on the level educational research and curriculum design, such assessment outcomes can help to design curricula and learning environments that are in accordance with students’ way of thinking about certain science concepts.

As already mentioned in the introduction, there are mainly two methods used for examining students’ conceptual knowledge: Interviews and open ended questionnaires. However, the most effective methods, like interviews are very time consuming and difficult to handle for teachers in classroom situations. Therefore, most existing optics tests use a simple multiple choice structure. Yet, this time-saving way of assessment it is not always able to identify students’ misconceptions as thoroughly as interviews do. In search for alternatives out of this dilemma, we encountered the method of two tier tests as used by e.g. Chandrasegaran, Treagust, & Mocerino, 2007, Tan, Goh, Chia, & Treagust, 2002; Peterson, Treagust, & Garnett, 1989, or Law & Treagust, 2008.

Two tier test items are items “that require an explanation or defence for the answer […] (see Wiggins and McTighe 1998, p. 14)” (Treagust, 2006). Each item consists of two parts, called tiers. The first part of the item is a multiple choice question which consists of distractors including known student alternative conceptions. In the second part of each item, students have to justify the choice made in tier one by choosing among several given reasons (Treagust, 2006).

Development of the Test Instrument

The present version of the test instrument was developed in two cycles. Each development cycle consisted of three stages following the procedure proposed by Treagust (1995) (Treagust, Glynn, & Duit, 1995): defining the content area of the study, identifying students’ conceptions and designing and validating test items.

Development Process – Cycle I

Based on the Austrian curriculum for year 8, the Austrian competence model for lower secondary and key ideas identified as conceptual basis for the understanding of geometrical optics (Guesne, 1985; Herdt, 1990) the following content areas were identified as relevant: propagation of light, process of vision, image formation by plane mirrors, image formation by converging lenses, image formation by refraction and colours. A special emphasis was put on the concept of vision conceptualized as a mechanism linking primary or secondary light sources sending off light to an observer who has a visual sensation when
receiving the light. This emphasis was based on the experience that solid a concept of vision turned out to be essential for understanding more advanced topics of geometrical optics like image formation and colours.

In a second stage students’ conception related to the key ideas mentioned above had to be identified. These alternative conceptions served as the basis for designing the distractors of the multiple choice items. In the first development cycle, the analysis of students’ conceptions was carried out in form of an intensive literature search, as thorough research had been carried out on students’ conceptions during the last three decades (Duit, 2009).

In the third stage of the first cycle, 26 multiple choice items were developed, consisting of three, four or five responses. The distractors of the items were based on students’ alternative conceptions which were taken from research literature. Ten out of this 26 multiple choice item consisted of one tier, 16 out of the 26 items had a two tier structure. The items were partly taken from already existing assessment tools for geometrical optics (Fetherstonhaugh & Treagust, 1992; Chen et al., 2002; Kutluay, 2005; Bardar et al., 2006; Chu et al., 2009) and were adopted and/or elaborated.

The first test version developed within this process described above was tried out empirically with N=643 year 8 students from different school-types and different Austrian regions. The test was administered online. In addition to the 26 test items, students and their teachers (N=22) were asked to fill in a questionnaire for accompanying research on the test instrument as well as on general and individual conditions of learning and instruction in their respective school environments. After analysing the test results of the first developmental cycle, the second cycle of test development was entered.

**Development Process – Cycle II**

The results of the first testing revealed potentials for improvement on several levels. Based on results of this first development cycle, the content for the test was redefined. The idea behind this was to concentrate on fewer key-ideas, as the huge amount of conceptions addressed had blown up the length of the test too much. So, we excluded the following key ideas for the second phase of testing: image formation by converging lenses, image formation by refraction and colours. At the same time an additional focus was put on the mechanism of absorption and selective re-emission of light by illuminated objects which function as secondary light sources. For this purpose test items had to be revised, redesigned or newly developed.

In order to identify typical student answers to those items developed for the second cycle as well as to items lacking a second tier, we carried out open ended questionnaires in two school classes. In addition, semi-structured interviews were conducted with year 8 students (N=10), after the instruction in geometrical optics. These interviews served several purposes: One intention was to gain a broad perspective of students’ ideas concerning the key concepts of geometrical optics addressed in our test instrument. Or to put it into other words, to make sure that the distractors which we had derived from research literature were exhaustive. Moreover, the interviews were supposed to help to determine and explore the response space of the newly developed items. Another big issue was the validation of the language and the graphical representations used in the items. As mentioned above, several items of cycle one had been taken from literature and already existing assessment tools which were originally in English in the majority of cases and had to be translated.

Next, the test version of cycle one was updated based on the results of the open-ended questionnaires, as well as on the semi-structured interviews. After a validation session with teachers and educational researchers, the final test version of cycle II was empirically tested.

**Participants & Setting**

The sample tested with the second test version included N=367 year 8 students, 169 female 196 male, one missing. The participants attended year 8 of High School or Grammar School and had a mean age of M_{age}=14.15 years (SD=4.65). The classes taking part in the second testing were pre-elected in the sense that we made sure in advance that all of the students had really had conventional instruction in
geometrical optics in year 8. In addition, we wanted to know the last mark in Physics, which can range from 1 (excellent) to 5 (fail) \( M_{\text{markPH}} = 2.25 \) (SD = 1.07). We also determined the self-concept in physics according to the PISA 2000 scale (Kunter et al., 2002) with a 4-category likert-scale (strongly agree – strongly disagree) as \( M_{\text{selfcPH}} = 2.50 \) (SD = 0.67).

Contrary to the empirical testing in development cycle one, we administered a paper and pencil test in a classroom setting this time. The experience of the first cycle had shown that not all school computer labs were equipped with the necessary number of computers so that in some cases two students had worked on one and the same computer at the same time.

3. Data and Findings

The aim of this paper is to portray the development process of our two tier test instrument on geometrical optics and to show some selected results of the current test version, which is the final version used in the second development cycle. Nevertheless, an overview of the results of the first development cycle needs to be given in order to motivate the changes made in the second cycle. As a consequence the Data & Findings section of this paper is divided into two parts: a first part that gives a brief summary of results achieved within the first test phase and a second part that shows selected results of the second test phase.

Findings of the first development cycle

The results of the first test version showed that several of those items taken from literature and existing tests did not work well for our target group. The tests of the 643 participants were analysed with SPSS. We got item solution frequencies ranging from 7.8% to 68.9% for the items consisting of one tier. Two tier items were considered as correct if both, the content and the reason part, were answered correctly. The solution frequencies for the two tier items were consequently considerably lower and varied between 2.7% and 21.1%. What is quite striking especially with some two tier items is the enormous amount of missing data e.g. 421 missings out of 643 participants. The reliability of the instrument was established by a Cronbach alpha coefficient of \( \alpha = 0.31 \), which is a not at all acceptable value.

The analysis of the accompanying research revealed three main week points of the test: Firstly, the forms of visual representations used (pictures, drawings,) as well as the fact that some items were quite text-intensive posed problems for students. Secondly, students as well as teachers showed a generally low motivation for participating in this study. Finally, the responses of the teachers involved showed that most key ideas of geometrical optics had just been partly taught, or had not been taught at all in the majority of cases.

Findings of the second development cycle

The final version of the second development cycle was tested in pre-selected classes. This time we asked teachers in advance if they had fulfilled the year 8 curriculum and had taught optics\(^1\). The responses of the 367 paper and pencil tests were typed in a SPSS matrix and analysed with this statistics software. As already mentioned above, the final test version of the second development cycle consisted of 20 two tier items and 6 items with only one tier.

The reliability of the subscale of the test instruments containing just two tier items was established by a Cronbach alpha coefficient of \( \alpha = 0.73 \), the reliability of the full scale, consisting of 20 two tier items plus 6 one-tier items, was established by a Cronbach alpha coefficient of \( \alpha = 0.77 \). An overview of the test and item statistics concerning the 20 two tier items is given in Table 1. There, the test and item statistics of two tier items are contrasted with those of all item tiers analysed individually (\( N_{\text{items}} = 46 \))\(^2\). This also gives an impression how the item design - whether one or two tiers are used - influences the test results.

When comparing the mean score achieved by the students, the difference between a two tier and a one tier based analysis becomes already obvious. On average, each student could answer 47.4% of the

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\(^1\) In general the content of the Austrian curriculum is obligatory, but as there is no external evaluation if the curriculum is fulfilled. So, especially topics which are traditionally taught at the end of the school year may be shortened.

\(^2\) 20 two tier items counted individually plus 6 one tier items
multiple choice questions in one tier form. When combining the multiple choice questions as two tier items, where students had to give the content asked for and the reason for their choice, students could answers on average only 37.2% of the items correctly. At this point it is important to mention that two tier items were only counted as correct, when the responses in both tiers were answered correctly.

Table 1. Test and item statistics of the final test version of the second development cycle

<table>
<thead>
<tr>
<th></th>
<th>Two-tier Items</th>
<th>One-tier Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>367</td>
<td>367</td>
</tr>
<tr>
<td>Number of items</td>
<td>20</td>
<td>46</td>
</tr>
<tr>
<td>Mean Score</td>
<td>7,43 (37,15%)</td>
<td>21,81 (47,41%)</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>3,26</td>
<td>7,29</td>
</tr>
<tr>
<td>Minimum/Maximum Score</td>
<td>1 (5%) – 18 (90%)</td>
<td>4 (8,70%) – 45 (97,83%)</td>
</tr>
<tr>
<td>Solution frequency</td>
<td>3% - 57,22%</td>
<td>8,45% - 88,28%</td>
</tr>
</tbody>
</table>

Item solution frequencies of the second testing cycle ranged from 8.5% to 88.3% for one tier items. The solution frequencies of the two tier items were again lower and varied between 3.0% and 57.2%. Compared to the final version of the first development cycle the number of missings was reduced to a quite acceptable rate, ranging from 0% to 4.9%.

The analysis also showed that the solution frequencies for some items were still low. A more detailed analysis of individual two tier items showed a significant difference between solution frequencies of the first and second tier of an item (see Figure 1). It is quite noticeable that in all cases the first tier is answered correctly by more students than the second tier.

Figure 1 shows selected items on the process of vision which we identified as a fundamental basis for the understanding of geometrical optics. In the first tier, the content tier, students had to select in which situations we do see objects, in the second tier, the reason tier, students have to find the scientifically most convincing argument, why we can see them.

The bar diagram in Figure 1 shows that in most items dealing with the process of vision students achieved quite a low solution frequency for both tiers answered correctly. Especially item SL1 has an outstanding difference in solution frequency between both tiers.

![Figure 1. Solution frequencies of the first, second and first plus second tiers of the items (SL1, LS1, EG1Tort, EG2) on vision](image)

In order got give a more detailed insight into the potential of the two tier structure this item shall be discussed in more detail. Item SL1 shown in Figure 2, addresses the concepts of vision and rectilinear propagation of light. 83.1% of the students were able to answer the first tier correctly. However, only 8.4% were able to give a correct answer finding all the factors accounting for why the lamp can be seen from
window C only. In total, only 6.3% of the students could solve both tiers of this item correctly.

When analysing the answers of the second tier in more detail, it becomes obvious that although more than 80% of the students could describe the phenomenon correctly (1st tier), only a small minority based their decision on a correct assumption concerning the mechanism of vision (2nd tier). Although all four answer options given are somehow relevant for the process of vision, only option 3 is the one giving an overall explanation for seeing the street-lamp.

A few students also ticked more than one answer and chose a combination of answer options. In the diagram (Figure 23), these cases are represented by a combination of the numbers of all options taken. We counted all answers as correct which contained option 3.

Distractors 1 and 4 are quite trivial ones, reproducing the conditions described in the item text anyway. Option 4 corresponds to Guesne’s (1985) “light bath idea” model. The most frequently taken option was “My view is not blocked by anything”. Even though a relationship between the lamp as secondary light source and the observer is established, the active part of the source emitting light and the passive part of the observer, who receives light, are reversed. Instead, vision plays an active role. This line of argumentation was categorized as “active eye” model by Guesne (1985).

Interesting is however that most students’ answers did not include option 3, which is called the “the physicists’ model” by Guesne (1985). This answer option does not only establish a correct relationship between the lamp as sender and the observer as receiver, it also contains the ideas of the other distractors: Light propagates rectilinear. Light from the lamp reaches my eyes, as the main ideas of distractors 1 and 2. Light reaches my eyes, so there is light there, as the main idea of distractor 4.

Figure 2. Item SL1a & SL1b focusing on the process of vision (adopted from Wiesner et al., 1995).
Figure 3. The bar diagram shows the distribution of response frequency for the four distractors of the second tier. Categories found by Guesne are related to the distractors.

4. Discussion and Conclusions

The comparison of the reliability of the final test version of the first development cycle and the final version of the second development cycle shows that the quality of the test items was improved. Above all, the students’ interviews and open questionnaires used to validate the language and the representations of the items, contributed a lot to this improvement.

When comparing both test versions two important points have to be mentioned. There are significant differences in item solution frequencies depending on the way of analysis. When all responses are counted individually the solution rates are much higher than when the analysis is carried out on basis of two tier items. This clearly shows that multiple choice tests with one tier items support randomly correct guessing. This can also be counted as a strong hint that one tier multiple choice items give just a superficial picture of students’ understanding. They give a rather one sided diagnosis of students’ conceptual knowledge as their emphasis clearly lies on knowing facts and not so much on giving reasons. The results achieved attest the two tier items a great potential to portray students’ conceptual knowledgebase, on the other hand.

What is still striking is the low solution frequency for some items. When comparing the content addressed in these items with teacher’s feedback on the importance of different key ideas, a correlation can be found. One interpretation is that conventional instruction does not put enough emphasis on certain key ideas of geometrical optics, like on the process of vision. The analysis of the items on vision shows clearly that students can account for most optical phenomena related to vision on basis of everyday experience, but they are not able to analyse them scientifically correct. The distribution of answers in the second tier, the reason tier, of the items on vision reproduces the categories of students’ concepts found by Guesne (1985) well. This indicates that the two tier structure of the multiple choice items helps to provide a deeper insight into students’ conceptual knowledge base than conventional multiple choice items do.

To sum it up, the analysis of the second test version shows on the one hand that the test is in general able to portray several types of students’ conceptions known from literature. On the other hand, results indicate that some items need still revision and improvement. Finally, items focusing on ideas like image formation by lenses or shadow formation need to be integrated in the current version to get a more
complex picture of the interaction between different conceptions. These findings will be included in a next version of the test.

References


Motivating Computational Physics Education using Rockets, Angry Birds and Colliding Galaxies

Wolfgang Christian1, Physics Department, Davidson College, Davidson NC, USA
Francisco Esquembre2, Mathematics Department, University of Murcia, Murcia, Spain
Anne Cox3, Physics Department, Eckerd College, St Petersburg FL, USA

Abstract

A computer-based modeling approach to teaching must be flexible because students and teachers have different skills and varying levels of preparation. Learning how to run the “software du jour” is not the primary goal of computational physics education. Learning computational thinking, how to use computation to communicate ideas, and how to design and build models is. We describe a no-cost open-source approach aligned with a modeling cycle pedagogy that does this [Christian 2011]. Our tools, curricular material, and ready-to-run examples are available at from the Open Source Physics Collection of the National Science Foundation funded ComPADRE National Science Digital Library [ComPADRE 2012].

Introduction

Current technologies allow physics educators the ability to combine traditional instruction with computational modeling. However, the implementation of a computational modeling pedagogy often requires a programming effort for teachers and students who want to use this approach. We have developed a platform that limits the amount of programming when designing, implementing, distributing, and using computational models. It is based on the integration of the Easy Java Simulations and the Tracker tools with the ComPADRE National Science Digital Library.

- Easy Java Simulations (EJS) is designed to create interactive simulations in Java (applications and applets) without the necessity of prior programming knowledge.
- Tracker is a video modeling tool that allows users to combine dynamical models with traditional video analysis.
- ComPADRE is an NSF-sponsored national digital library that is a collaboration of the American Association of Physics Teachers, the American Physical Society, and the American Institute of Physics.

This paper outlines the pedagogical and technical features of the OSP project and how we use OSP-based tools and resources to introduce modeling into the curriculum. We describe our current effort to create and distribute new material using the Easy Java Simulations and Tracker tools and how we distribute this curricular material with ComPADRE National Science Digital Library [OSP 2009].

Methods

Physics education has become an important research topic in the last few decades [Redish 2003]. The increasing interest in exploring new teaching methods in physics has its roots in: 1) the realization that interactive engagement teaching pedagogies improve learning, and 2) the desire to incorporate current technologies and current professional practice into curricula. Computational physics education has much to gain from the synthesis of these new learning pedagogies and tools [Christian 2008].

1 Partial funding for this work was obtained through NSF grant DUE-0442581.
2 Partial funding for this work was obtained through Spanish Ministry of Science project DPI 2007-61068 and project 03/CS10 of the Seneca Foundation of the Region of Murcia.
3 Partial funding for this work was obtained through NSF grant DUE-0442581.
The modeling approach to teaching is a research-proven pedagogy that predates computers. It attempts to enhance student achievement through a process called the Modeling Cycle. The Modeling Cycle was pioneered by Robert Karplus [Fuller 2001] and the SCIS Project in the 1960s and 70s and later extended by the Modeling Instruction Program led by Jane Jackson and David Hestenes at Arizona State University [Jackson 2008].

The goal of modeling is to teach in a student-centered environment where students do not solve problems in a formula-centered way. The start of the modeling cycle is the development of the model by:

- Qualitative description
- Identification of variables
- Planning an experiment
- Performing the experiment
- Analysis of the experiment
- Presentation of results
- Generalization

After development, the model is employed to study a variety of new physical situations in a variety of ways to test, expand, and enrich the student-created model.

Although the Modeling Cycle can be used without computers, it is well suited for computer modeling if we replace the word “experiment” with “simulation” in the development phase. The analysis of a computer simulation is, in fact, similar to that of a laboratory and often provides the student with a novel perspective on the behavior of a system. Furthermore, the use of computers allows students to study problems that are very difficult and time consuming to study experimentally, to visualize their results, and to communicate their results with others.

The Modeling Cycle approach has been shown to correct weaknesses of traditional instruction by actively engaging students in the design of physical models that describe, explain, and predict phenomena. It is believed that the combination of computer modeling, theory, and experiment can achieve insight and understanding that cannot be achieved with only one approach.

**Platform and Findings:**

**Easy Java Simulations** (EJS) is a Java-based authoring tool that offers a range of possibilities that allow teachers to pick their level of student engagement. Teachers may: use/modify existing simulations for their teaching; distribute ready-to-run JAVA simulations to students for visualization purposes; distribute partially constructed or flawed models that students must edit and return; or construct broad assignments for students to create models from scratch.

The architecture of EJS shown in Figure 1 is based on the model-view-control (MVC) design pattern with documentation, where a simulation is composed of:

- The computational model which implements the phenomena under study in terms of
  - Variables and parameters that describe the state of the system.
  - Algorithms, such as ODE solvers, that advance the state of the model.
  - Relations among variables, such as the conservation laws in physics.
- The control which defines actions that a user can perform on the simulation.
- The view which shows a graphical representation (either realistic or schematic) of the model and its data.
• The description which provides an opportunity for the author to document the model’s theory, assumptions, and range of validity.

Figure 1. An EJS-based computational physics exercise. A template is provided and students are required to provide the computational details [Englehardt 2011].

A user interface is constructed by dragging and dropping control and visualization components from a palette onto the model. While some programming knowledge is assumed, users are encouraged to focus on the computational implementation using either ODE notation within a differential equation editor (see Figure 1) or explicit Java code.

After a model is built, documented, and tested within EJS, the model (including its non-Java resources such as graphics and html description pages) is packaged for distribution into either a jar file or a zip file by clicking on a button within EJS. The resulting jar file, about 1 Mbyte for the pendulum model above, is a stand-alone Java application that does not require EJS and can run on any computer with a Java VM. The model’s html documentation appears within a viewing frame and can links to PDF documents within the jar open in a native viewer. If a zip package is selected, the resulting 10 Kbyte archive contains the XML source code and other resources but must be unzipped on a computer with EJS to run.

Because an EJS XML source code file is small, the stand-alone jar file also contains this resource. The immediate availability of the code provides one of the most powerful and exciting aspects of EJS models. Unlike most compiled programs, users can examine, modify, and redistribute the model with minimal effort. Right-clicking within a running simulation displays a pop-up menu with the option to extract the XML file from the jar and to copy it into the local computer’s EJS workspace. This packaging trick allows a teacher to ask students to modify a compiled model and repackage it, thereby creating a teacher-student feedback loop that supports the Modeling Cycle.

Tracker is a video analysis and modeling tool that enables students to create dynamical models that are drawn directly on videos of real-world phenomena (Figure 2). Because the simulations and videos share the same time base and coordinate system, students can test their models experimentally by direct visual inspection, a process that is both intuitive and discerning. In effect, the videos make the models more “real” while the models make the videos more understandable. Additional views of model-generated data such as plots and tables are also available for analysis, and a tabbed page view enables authors to include html documentation, instructions, exercises, etc.
Figure 2. A student Tracker exercise to determine the physics of Angry Birds.

Tracker’s “Model Builder” workpanel (Figure 3) provides a gentle introduction to dynamical modeling by making it easy to simulate a particle that obeys Newton’s laws. Students define and modify the force expressions, parameter values and initial conditions, and the model particle is automatically drawn on the video. The expression parser accepts all common mathematical functions. The motion is computed with an ODE solver using a Runge-Kutta algorithm but these numerical details are hidden from students so their learning focus is on the forces and resulting behavior. Unlimited undo/redo and instant visual feedback encourage interactive exploration of models, and even small visual discrepancies can illustrate the limitations of overly simplified models or video distortions.

The process of identifying pertinent forces, defining appropriate expressions and comparing models visually by overlaying videos supports the modeling cycle paradigm in a way that is both rigorous and accessible even to students with no prior computational modeling experience and/or limited data analysis skills. But since Tracker also provides traditional video analysis functionality, more advanced students can compare models with data obtained from manual or automatic tracking of objects within videos.

If the video and html files reside on remote servers, Tracker can open a trk file locally or from the web and load all needed resources. Another packaging option is to compress the trk, video and html files into a single zip file with the same name as the trk—Tracker will open the zip file and extract all resources automatically. In this way teachers and students can create video modeling experiments from scratch or open a trk file to start with a video, instructions and potentially partial (or incorrect!) models. Completed student models can of course be saved in new trk files.

Combining the model-building power of EJS with Tracker’s ability to synchronize, scale and overlay models on videos is an exciting extension of OSP computer modeling currently under development. Because the video format is so familiar to students yet contains such a wealth of spatial and temporal data, direct comparison of raw or enhanced videos with model animations is possible in many areas of physics. Such a combination supports both model development and model testing in the Modeling Cycle.
Figure 3. Model Builder with a dynamical model of a simple projectile.

ComPADRE [ComPADRE 2012] is a growing network of online National Science Digital Library Pathway containing educational resources supporting teachers and students in Physics and Astronomy. Each ComPADRE collection is focused on a particular community (e.g., high school teachers, physics majors, physics education researcher) or topic (e.g., quantum physics, astronomy).

Figure 4. The Colliding Galaxies model shown is accessible from a browser and from within EJS.

The Open Source Physics (OSP) Collection within ComPADRE contains Java-based computational resources for teaching and the supporting documentation to help teachers and students take advantage of these
materials. The goal of our collection is to provide curriculum resources that engage users in physics, computation, and computer modeling. The Colliding Galaxies model shown in Figure 4, for example, is a student project that is based on model studied by Tomere at the Pittsburgh Supercomputing Center [Toomer 1972].

The OSP collection is built on a repository of source code, executable simulations, and curriculum resources. As with any good library, these items are annotated and cataloged so that users can find materials using standard search criteria such as subject, author, and keyword. Other library and web tools are available to the OSP Collection as a part of ComPADRE. These include personal user collections (both private and shared), comments on resources, connections between resources, and the easy incorporation of OSP and EJS pedagogical materials into all other ComPADRE collections.

The collaboration between the OSP and ComPADRE projects has resulted in a new way of sharing EJS models over the web. The EJS modeling environment can act as a client that directly accesses and downloads models in the ComPADRE library. Clicking on the web libraries icon in EJS connects to online repositories and displays a catalog of models in a table of contents as shown in Figure 4. Clicking a catalog entry shows a brief description of that model. Double-clicking either the catalog entry or the download button copies the model’s XML source code and resources from the library into the local EJS workspace where it can be examined and modified.

Although the OSP Library on ComPADRE is a large central repository of resources, EJS developers have the option of sharing their materials through this same web-client interface. This will give teachers and students access to more resources and also different organizational structures for EJS models. For example, the ComPADRE models are arranged by subject while the Davidson College EJS digital library shows models arranged by course syllabus.

**Discussion and Conclusions**

EJS and Tracker models in the ComPADRE digital library with associated curricular materials have the following pedagogical benefits:

- **They help students visualize abstract concepts.** The most obvious benefit of simulations in instruction is that they help students visualize systems. In traditional instruction, students learn the concepts of physical science and physics via static pictures and words. Students construct an understanding through internal visualization, which is usually faulty for new topics and will hamper their progress toward understanding the concepts of physics.

- **They are interactive and require student control.** Students often learn to use a “plug-n-chug” approach to problem solving. When faced with end-of-the-chapter textbook problems, students quickly determine that through a process of elimination, they can find the appropriate equation to use to solve these problems without relying on the physics concepts [Maloney 1994]. In well-designed model-based simulations, physical quantities are not given and must be determined from the simulation. Since determining what information is relevant must be done early in the problem-solving process, students must conceptualize the problem before starting algebraic manipulation.

- **They are more like real-world problems.** Textbook problems are very different from real-world problems. Solving a real-world problem entails distinguishing between relevant and irrelevant information. In a model-based simulation, just as in a laboratory, students must take data that introduces and reinforces the idea that there is uncertainty in measurements and therefore results. This means that two students when faced with the same model-based simulation will end up with slightly different (correct) answers. Using simulations can therefore bridge the gap between theory and the real world [Ronen 2000].

- **They use multiple representations to depict information.** The idea that students learn best when they see the same ideas presented in different ways is not new. Traditional instruction relies on the written and spoken word and other static depictions. Simulations can not only
depict motion, but they can also simultaneously depict the information in a different way via graphs and tables that change with time [Van Heuvelen 2001]. In addition, simulations can provide the opportunity to investigate numerous alternate scenarios [Zacharia 2003].

- **They are simple with limited distracting features.** Educational materials are too often developed based on technology with pedagogy as an afterthought. Only graphics, animations, or sounds that contribute to the learning process should be included in a simulation. This allows students to focus in the task without being distracted by unnecessary or overly flashy additions.

- **They can improve assessment of student understanding.** Researchers have shown that simulation-based resources can provide a superior assessment vehicle as compared to traditional paper-based questions. Dancy compared student responses to traditional conceptual exercises with responses to nearly identical simulation-based exercises. She found that, in general, the simulation-based version of the exercise was more valid for understanding whether students understood a given concept [Dancy 2002].

The combination of a computational physics friendly modeling and authoring tools with Internet technologies allows teachers to easily incorporate computer-based modeling into their curriculum by providing an open and extensible solution for the creation and distribution of educational software. EJS and Tracker are free because they are collaboratively built and released under the GNU GPL software license. ComPADRE has no registration costs because it is part of the National Science Digital Library project and endorsed and supported by the professional societies. Our curriculum modules are extensible, adaptable, and easily modifiable. If a model is uploaded into ComPADRE, its authorship, modifications, and use are documented and intellectually traceable.

The advantage of EJS and Tracker for physics teaching is that it forces students to separate the model into logical parts and to separate the mathematics from the visualization. Students learn the logic of modeling using loops and control structures and study algorithms used in professional practice. Students are introduced to programming concepts but user-interface coding is not required.

The Open Source Physics combination of computational physics tools and computer modeling pedagogy with a digital library provides students and teachers with new ways to understand, describe, explain, and predict physical phenomena. Despite its current focus on upper-level physics, the OSP Collection serves thousands each month. During March 2011 we served 10,000+ visitors over 5,000 simulations - an increase of 32% over March 2010 traffic. We find user loyalty is increasing as well - over 2,500 different users visited at least 8 times between January-March 2011, an 80% increase from January-March 2010 and an indication of the project’s increasing visibility to educators.

**Acknowledgements**

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Prospective Science Teachers’ Misconceptions about Energy

Dilek Erduran Avcı, Mehmet Akif Ersoy University, Education Faculty Science Education Department, Burdur/Turkey. corresponding author e-mail: derduran@mehmetakif.edu.tr
Dilek Karaca, Science teacher, Adana/Turkey.

Abstract

‘Energy’ is one of the most important key scientific concepts. An inspection of Turkish science curriculum reveals that energy concept occupies a wide place from all grades in many teaching units. The purpose of this study is to examine the prospective science teachers’ understanding of the concept of energy and reveal the misconceptions if any existed. The participants were 131 prospective science teachers. They were addressed three questions. These questions inquire the concepts of mechanical energy, kinetic energy, potential energy, and the relations among above three. Each of the questions has three stages. The participants were asked to pick the right choice, to justify their selection, and to state their level of certainty. It was observed that almost 30% of prospective science teachers had misconceptions about kinetic energy and potential energy. Almost half of them successfully related mechanical energy to kinetic and potential energy. Other half had one of the misconceptions “mechanical energy is related to the velocity”, “mechanical energy is related to the distance”, and “mechanical energy is the sum of change in the energy”. The participants which successfully answered the questions about concepts of kinetic and potential energy stated that they were ‘strongly sure’ or ‘sure’ about their answers. When the certainty levels of the question about mechanical energy concept are examined, it was found out that half of the students were not sure of their explanations where the other half was ‘sure’ or ‘strongly sure’ of their explanations. Prospective science teachers, who have some misconceptions about science concepts, may sustain their misconceptions as future teachers. This possibility raise the idea of their future students share their recent misconceptions. The researchers think that awareness and correction of teacher candidates’ misconceptions about key science concepts would contribute to training of future generations as science literate individuals.

Keywords: Energy, misconceptions, teacher candidates.

Introduction

In today’s world, science literacy has a strong position in the science education standards (National Research Council, 1996; Federated States of Micronesia, 2008) and curriculum (National Curriculum Board, 2009; Turkish Ministry of National Education 2005a, 2005b; Park, Park & Lee, 2009) of many counties. An important dimension of science literacy is gaining “an understanding of key scientific terms and concepts” (Miller, 1983). In most of the studies about science literacy, importance of ‘gaining knowledge of science concepts and understand them’ is emphasized. It is common information that in order to grow students who learn and understand scientific concepts, we need teachers/teacher candidates who know and understand the concepts exactly.

Science education aims to make students gain the information and capability about the units in the curriculum. The units include concepts and theories. Therefore, the key points in science education are, understanding the concepts and building the interconceptual relations correctly. Such a comprehension leads to correct appliance of gained information to real life and to encountered problems. So, conceptual learning is of great importance in science education (Cerit-Berber, 2008).

Ayas et al. (1997) stated the reasons of placing concept teaching in science education as follows:

1. Contemporary teaching approaches accept that permanent learning is conceptual, not mathematical.

2. Information, which is gained by students by their daily life and previous experiences, greatly influences the future learning. Especially, if a student has misconceptions in the past, this fact has a negative impact on learning new information.
3. As the inevitable conclusion of the advances in science and technology, new information is discovered every day. This occurs in such a pace that it goes beyond the interception rate of humans. Therefore, learning basic concepts correctly becomes more important than ever.

4. Without correcting the misconceptions of students, which emerge from their previous education or interaction with the environment, scientifically acceptable conceptual learning cannot be achieved.

‘Energy’ is one of the most important key science concepts. It exists in both scientific domain and in science-technology-society-environment relations. In addition, it can be found out that, this concept takes place widely in Turkish science and technology curriculum from 4th to 8th grade in scattered into numerous units. On the other hand, concept of energy is one of the concepts which students experience difficulty to understand (Stylianidou, Ormerod, & Ogborn, 2002). Hırça (2008) states two reasons for students’ misconception about energy. First, as emphasized in Watts (1983), students are accustomed to energy concept and they have a prejudice about it in their minds. Second, as stated by Duit (1984) and Warren (1986), energy cannot be defined exactly. Defining energy as ‘the capacity to perform work’ makes students misunderstand the concept. Such a definition makes students cannot understand the principal of conservation of energy. This leads to growing students who are not able to evaluate mechanical systems from conservation of energy perspective.

There are several studies that focus on misconceptions and learning difficulties of students and teacher candidates from different levels about energy concept (Cerit-Berber, 2008; Hırça, 2008; Yürümezoğulları, Ayaz, & Çökelez, 2009; Cerit-Berber & Sari, 2009; Gülçöek, 2002; Ünal-Çoban, Aktamış, & Ergin, 2007). According to Baysen, Güneyli and Baysen (2012), a portion of misconceptions can be regarded natural but the rest root from faulty education (selected method, technique, material and language) and instructors who have misconceptions. In this context, finding out the misconceptions of future instructors and correcting these misconceptions is of great importance. Therefore, this study is significant in terms of finding out the misconceptions of candidates about the concept of “energy”, which is a prime concept of science. This research aims to examine the prospective science teachers’ understanding of the concept of energy and reveal the misconceptions. Within the purposes of the study, the following questions were investigated:

- What is the prospective science teachers’ understanding level of the concept of ‘kinetic energy’, ‘potential energy’, and ‘mechanical energy’?
- What are the prospective science teachers’ misconceptions about the concept of ‘kinetic energy’, ‘potential energy’, and ‘mechanical energy’ if any existed?

**Methods**

**Participants**

The participants were 131 teacher candidates of Mehmet Akif University Science Teacher Program who were in their freshmen year during 2009-2010 educational year. All the participants were registered to “General Physics I” course and were successful.

**Data collection tool**

Teacher candidates were addressed three questions. These questions inquire the concepts of mechanical energy, kinetic energy, potential energy, and the relations among above three. The questions which were prepared by the researchers include examples from daily life. Each of the questions had three stages. In the first phase, teacher candidates marked the choice which they believed to be true. In the second phase, they explained their justification. Finally they defined their level of certainty (strongly sure, sure, not sure, I do not know). Three physics education experts were consulted to find out the levels of questions’ ability to reveal the misconceptions, understandability and accuracy. Questions were rearranged according to the experts’ advices before application.

WCPE 2012, Istanbul, Turkey
Analysis of data

Analysis of data was performed in three phases. In the first phase, answers to the questions were grouped according to the choices. In the second phase, justifications to the choices were examined. Using content analysis, similar justifications were grouped producing common statements. These statements were inspected by two field experts. It was found out that, experts were in total (100%) agreement with the researchers. In the final phase, level of certainty was inspected. Tables, which reflect the choices teacher candidates selected, their justifications, and their level of certainty, were prepared and presented.

Data and findings

In order to determine the participants’ level of understanding about energy concept and find out any possible misconceptions, participants’ answers and justifications were examined. In this section, teacher candidates’ understanding and misconceptions about kinetic energy, potential energy, and mechanical energy are presented.

Understanding the concept of kinetic energy

First question, which is about kinetic energy, is presented below. Answers to this question and percentage/frequencies of the answers are given in table 1.

Table 1. Distribution of answers to question about kinetic energy

<table>
<thead>
<tr>
<th>Choices</th>
<th>Justification</th>
<th>Level of certainty</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1 &gt; K_2 &gt; K_3$</td>
<td>An object’s kinetic energy is inversely proportional to the length of the route.</td>
<td>SS: 4</td>
<td>S: 18</td>
<td>NS: 4</td>
</tr>
<tr>
<td>$K_3 &gt; K_2 &gt; K_1$</td>
<td>An object’s kinetic energy is proportional to the length of the route / An object’s kinetic energy is relational to the shape of the route.</td>
<td>-</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>$K_2 &gt; K_1 = K_3$</td>
<td>It depends on the shape of the slide.</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>$K_1 = K_2 &gt; K_3$</td>
<td>Kinetic energy and velocity is proportional.</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$K_1 = K_2 = K_3$</td>
<td>Masses released from the same altitude hit to the ground at the same moment.</td>
<td>39</td>
<td>40</td>
<td>10</td>
</tr>
</tbody>
</table>

SS: Strongly sure; S: Sure; NS: Not sure, DNK: Do not know; *Correct choice, n: number of teacher candidates
67.94% of the teacher candidates chose the correct option \((K_1 = K_2 = K_3)\) and justified it typing ‘masses released from the same altitude hit to the ground at the same moment’. 21.37% stated that an object’s kinetic energy is inversely proportional to the length of the route where 8% stated that an object’s kinetic energy is proportional to the length of the route. Samples from statements of teacher candidates are provided below:

“Distance does not matter. Only important point is that they are released from the same height. It is because potential energy is transformed into kinetic energy and lack of friction makes the energy conserved.”

“The person using first slide directly descends to water but the person in the second slide cannot descend directly because of the shape of the slides. The bumps in the slide slow him down. The person in the third slide almost stops when he arrives to the turning point and loses speed.”

“Since the distance is different, velocity \((v)\) would be different.”

“Kinetic energy is related to mass and velocity. Their masses are same but velocities are different. The person on the first slide descends fastest. The sections in the second slide and the turning point in the third slide have a decreasing effect on speed.”

“Kinetic energy is related to distance not height. Since the route is different, velocities are different. Since velocities are different, kinetic energies are also different.”

“Proportional to the length of the routes, kinetic energy has changed. The longer route makes more speed.”

“\(K=\frac{1}{2}mv^2\), they have the same mass and release themselves at the same moment but their velocities are different because of their routes. Therefore the one with the longer distance would have a greater kinetic energy.”

67.94% of the teacher candidates successfully related the concept of kinetic energy to the mass, speed and altitude of an object. Almost 30% of the teacher candidates possessed the misconceptions “kinetic energy of an object is inversely proportional to the distance”, “kinetic energy of an object is proportional to the distance”, and “kinetic energy of an object depends on the shape of the route”. Out of the 89 teacher candidates who picked the right choice, 39 selected ‘strongly sure’, 40 selected ‘sure’, and 10 selected ‘not sure’. None of them selected ‘do not know’. Out of the 42 teacher candidates, who have misconceptions, 5 selected ‘strongly sure’, 28 selected ‘sure’, 7 selected ‘not sure’, and 2 selected ‘do not know’.

**Understanding the concept of potential energy**

Second question, which is about potential energy, is presented below. Answers to this question and percentage/frequencies of the answers are given in table 2.

**Question 2.** Persons with masses m1, m2, and m3 release themselves from slides 1, 2, and 3 respectively. Which one of the following statements can not be told about the change of potential energy of these people?
Table 2. Distribution of answers to question about potential energy

<table>
<thead>
<tr>
<th>Choices</th>
<th>Justification</th>
<th>Level of certainty</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>If $m_3 &gt; m_2 &gt; m_1$, the greatest potential energy change occurs in slide 3.</td>
<td>Change in the potential energy is related to the distance, not mass.</td>
<td>SS 8 S 3 NS 1 DNK 6</td>
<td>4.58</td>
<td></td>
</tr>
<tr>
<td>If $m_2 &gt; m_1 = m_3$, the greatest potential energy change occurs in the slide.</td>
<td>They have different shapes, therefore different heights.</td>
<td>SS 1 S 1 NS 1 DNK 3</td>
<td>2.29</td>
<td></td>
</tr>
<tr>
<td>If $m_1 = m_2 = m_3$, all the potential energy changes are equal.</td>
<td>Since the distances/times of their arrival to the ground are not equal, potential energy changes cannot be the same.</td>
<td>SS 7 S 13 NS 7 DNK 2</td>
<td>29</td>
<td>22.14</td>
</tr>
<tr>
<td>Even $m_1$, $m_2$, $m_3$ are known, it is not sufficient to make a comparison of potential energy changes.*</td>
<td>Only if the masses are known a comparison can be made because gravity and altitudes are equal.</td>
<td>SS 53 S 29 NS 6 DNK 5</td>
<td>93</td>
<td>70.99</td>
</tr>
</tbody>
</table>

70.99% of the teacher candidates selected the correct answer to the second question, stating that only if the masses are known a comparison can be made because gravity and altitudes are equal. 22.14% of them stated that since the distances/times of their arrival to the ground are not equal, potential energy changes cannot be the same. 6.87% of them stated that distances and velocities of the masses should be known to make such a comparison. Although it is emphasized that the slides had same height in the question body, 2.29% of them insist that shape of the slides would change the altitudes of the slides. Inspection of the wrong answers reveals that they have misconceptions like ‘potential energy of an object is related to distance’ or ‘potential energy of an object is related to the velocity’. Samples from statements of teacher candidates are provided below:

“Potential energy (PE) is $mgh$. Here, $h$ (height) and $m$ (mass) are important. In two of the slides, there are descending and ascending parts. Therefore $h$ changes and so does the potential energy.”

“Even the masses are equal, heights and reaching times to the ground are not. Therefore potential energy changes cannot be equal.”

“Even the masses are equal; we have no information about the distances. Therefore potential energy changes cannot be equal.”

“…..because of the shapes of the slides, potential energy changes cannot be equal.”

“Since we do not know their velocities, we cannot say that their potential energy changes are the same.”

“Potential energy is related to mass, gravity and altitude. The altitude and gravity are equal. Therefore a comparison can be performed only if the masses are known.”

Out of the 93 teacher candidates who picked the right choice, 53 selected ‘strongly sure’, 29 selected ‘sure’, 6 selected ‘not sure’, and 5 selected ‘do not know’. Out of the 38 teacher candidates, who have misconceptions, 10 selected ‘strongly sure’, 14 selected ‘sure’, 11 selected ‘not sure’, and 3 selected ‘do not know’. From both groups, majority of the participants selected ‘strongly sure’ and ‘sure’ options, resembling their confidence.
**Understanding the concept of mechanical energy**

Third question, which is about mechanical energy, is presented below. Answers to this question and percentage/frequencies of the answers are given in table 3.

Table 3. Distribution of answers to question about mechanical energy

<table>
<thead>
<tr>
<th>Choices</th>
<th>Justification</th>
<th>Level of certainty</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>The greatest change in mechanical energy occurs in slide 1.</td>
<td>Mechanical energy is proportional to velocity.</td>
<td>2  13  6  2  23</td>
<td>17.55</td>
<td></td>
</tr>
<tr>
<td>The greatest change in mechanical energy occurs in slide 3.</td>
<td>Mechanical energy depends on distance.</td>
<td>-  4  5  1  10</td>
<td>7.63</td>
<td></td>
</tr>
<tr>
<td>Mechanical energy does not change.*</td>
<td>Since there is no friction, potential energy will transform into kinetic energy and mechanical energy will be preserved.</td>
<td>17 11 14 18 60</td>
<td>45.80</td>
<td></td>
</tr>
<tr>
<td>Mechanical energy changes in all slides at the same rate.</td>
<td>Since all of the potential energy will transform into kinetic energy, mechanical energy will change in the same rate.</td>
<td>6 13 5 9 33</td>
<td>25.19</td>
<td></td>
</tr>
</tbody>
</table>

45.8% of the teacher candidates selected the correct answer to the third question, stating that potential energy would transform into kinetic energy, preserving the total energy, which is the mechanical energy, in the system. 25.19% of them stated that all the potential energy would transform into kinetic energy and that was the mechanical energy. 17.55% of them related mechanical energy to velocity where 7.63% of them related it to distance. 5 candidates did not answer this question.

Inspection of the wrong answers reveals that most of the candidates who have misconceptions considered ‘mechanical energy’ and ‘mechanical energy change’ the same and used instead of each other. Samples from statements of teacher candidates are provided below:

“Since K+PE=ME (mecaniuml energy), energy always transform from one form to another. Energy is not lost. Mass and altitude is same, so energy change is the same.”

“PE=mgh. So, if h is the same before release, PE is the same for all slides. After release, E<sub>start</sub> would be equal to E<sub>end</sub>=K so the change would be PE.”

“Here, K+PE=ME and PE=K so it is the conservation of energy law. Then they would change at the same rate.”

“ME is the sum of energy change. Energies, altitude, mass, and gravity are the same so all change at the same rate.”

“When we apply the formula mgh=1/2 mv^2, m is the same and g, h ve v are always constant. So the total energy does not change and remains the same.”

“ME=PE+K, therefore when the person slides down from the slides, his PE transforms into KE.”

“ME=PE+K. There is no friction so PE transforms into kinetic energy and ME does not change.”

“Since he makes a bigger distance in slide 3, ME changes.”

“PE is the same in all three but slide 3 has the greatest K. Therefore the greatest ME change occurs in slide 3.”
“The person slides down from the slide 3 fastest. At the beginning, all PE are the same but slide 3 has the greatest K so ME change is the greatest.”

“Slide 1 has the greatest velocity so greatest ME is in slide 1.”

“Here, since mass, gravity, and altitude are the same, energy change is only related to velocity. In my opinion, the greatest change occurs in slide 1 because the greatest speed happens there.”

“ME=PE+K. When we have a look at the slides, in 2 and 3 there would be a decrease in speed.”

Almost half of the teacher candidates successfully related mechanical energy to kinetic and potential energy. Other half had one of the misconceptions “mechanical energy is related to the velocity”, “mechanical energy is related to the distance”, and “mechanical energy is the sum of change in the energy”.

Out of the 60 teacher candidates who picked the right choice, 17 selected ‘strongly sure’, 11 selected ‘sure’, 14 selected ‘not sure’, and 18 selected ‘do not know’. Out of the 66 teacher candidates, who have misconceptions, 8 selected ‘strongly sure’, 33 selected ‘sure’, 16 selected ‘not sure’, and 11 selected ‘do not know’. It is interesting that most of the students who answered the question correctly selected ‘do not know’ and most of the students who answered the question incorrectly selected ‘sure’.

Discussion and conclusion

This research aimed to find out the misconceptions of science and technology teacher candidates about the ‘kinetic energy’, ‘potential energy’, and ‘mechanical energy’ concepts. The participants were addressed three questions about three slides with different shapes. The participants were asked to pick the right choice, to justify their selection, and to state their level of certainty. Using the data gathered from the participants’ answers and justifications, researchers determined the misconceptions of the participants about the target concepts.

First question was about kinetic energies of three people with same masses three at the moment of plunging into water who sled down from three different slides. 68% of teacher candidates related kinetic energy to mass, velocity, and altitude correctly. On the other hand, it was observed that almost 30% of teacher candidates had misconceptions like ‘an object’s kinetic energy is inversely proportional to distance’, ‘an object’s kinetic energy is proportional to the distance’, or ‘an object’s kinetic energy depends on the shape of the route’. It was observed from the justifications of teacher candidates that they thought the masses would have different velocities because of different distances; so kinetic energies would be different. This finding was parallel to Ayvacı and Devecioğlu (2009)’s conclusions which stated that students experience trouble in relating kinetic energy to velocity.

Second question questioned the change of potential energies of three different people with different masses who sled down from three different slides. 71% of teacher candidates related potential energy to mass and altitude correctly. On the other hand, it was observed that almost 28% of teacher candidates had misconceptions like ‘an object’s potential energy change is related to the distance’, or ‘an object’s potential energy change depends on the velocity’. Although it was clearly stated in the question body that slides had the same altitude, some teacher candidates emphasized that different shapes of the slides would affect the altitude. Hırça et al. (2011) also found out that there were students with the misconception ‘masses which climb up to the same altitude from different distances gain different potential energies’. Our result was similar to this finding.

In third question, teacher candidates’ understanding level of mechanical energy change was inspected. Almost half of teacher candidates related mechanical energy to kinetic and potential energy correctly. The rest had misconceptions like ‘mechanical energy depends on the distance’, ‘mechanical energy is proportional to velocity’, or ‘mechanical energy is the sum of energy change’. In addition, a portion of the teacher candidates considered mechanical energy change as the transformation of potential energy to kinetic energy. Using the justifications of the answers to this question, it can be stated that participants confused the concepts ‘mechanical energy’ and ‘mechanical energy change’ and used them on behalf of each other. Our findings are similar to Gülçiçek and Yağbasan (2004a) and Ayvacı and Devecioğlu (2009), which emphasize that students were not aware of the fact that mechanical energy is the sum of potential
energy and kinetic energy and did not realize how a change in one energy form would affect the other energy forms in a system.

In the literature about energy concept there are both domestic and international studies which state that students have difficulties in related concepts to another concept and misconceptions occur frequently. Results of our study are in parallel to the related literature (Erduran-Avcı, Ünlü & Yağbasan, 2009; Adamczyk & Wilson, 1999; Bahar et al., 2002; Gülçiçek & Yağbasan, 2004b; Watts, 1983; Nicholls & Ogborn, 1993; Goldring & Osborne, 1994; Edens & Potter, 2003; Ünal-Çoban et al., 2007; Hırça et al., 2008).

It is noticed that the teacher candidates, who answered the questions correctly, mostly preferred ‘strongly sure’ and ‘sure’ for the first and the second questions where they preferred ‘not sure’ and ‘do not know’ for the last question. This made the researchers think that teacher candidates had more difficulty in understanding mechanical energy change than understanding kinetic energy or potential energy. On the other hand, teacher candidates who had misconceptions mostly preferred ‘strongly sure’ and ‘sure’ for all three questions. This result was considered as their confidence in their knowledge was high even they had misconceptions. This finding was similar to Erduran-Avcı, Kara & Karaca (2012), which revealed that the teacher candidates, who had misconceptions about work, preferred ‘strongly sure’ and ‘sure’ rather than ‘not sure’ and ‘do not know’.

Teacher candidates, who have some misconceptions about science concepts, may sustain their misconceptions as future teachers. This possibility raise the idea of their future students share their recent misconceptions. The researchers think that awareness and correction of teacher candidates’ misconceptions about key science concepts would contribute to training of future generations as science literate individuals.

References


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An Investigation of Prospective Teachers’ Views on Implementing a Science Writing Heuristics in Physics Laboratories

Dilek Erduran Avcı, Mehmet Akif Ersoy University, Education Faculty Science Education Department, Burdur, Turkey, derduran@mehmetakif.edu.tr
Dilek Karaca, Science teacher, Adana, Turkey.
Tolga Akçay, Şanlıurfa Merkez Yeniköy Middle School, Şanlıurfa, Turkey.

Abstract

Inquiry research techniques are one of the crucial supporters of science lab. In recent years, one of the research-inquiry-writing techniques used in laboratory activities is science writing heuristic (SWH). The purpose of this study is to examine the views of prospective teachers using SWH template and traditional laboratory report format in General Physics Laboratory-I course. 32 teacher candidates participated in the research educating in Science Teaching Education Department. A semi-structured interview form was used as the data collection tool. Data was analyzed using content analysis. According to the findings of the study, both SWH templates and traditional laboratory reports were found to be supporting the education process. Participants, who used the SWH templates, emphasized that they were able to import their physics knowledge to their daily life better, they grew a positive attitude towards physics, they felt more self-confident, and they were able to express their opinions better. Teacher candidates who participated in peer assessment stated that peer assessment had a positive affect on their success grades. On the other hand, both groups using SWH templates and traditional laboratory report format have positive attitude towards General Physics Laboratory-I.

Keywords: Physics laboratory, science writing heuristic, student template, prospective teachers.

Introduction

Due to the rapid developments in science and technology, contemporary societies require individuals who are able to use information and technology efficiently (Kahyaoğlu, 2011). In order to understand and make use of new technologies and information, individuals and societies should be science literate (Özdemir, 2010). A science literate individual can make personal decisions about social, cultural, and economic efficiency and possesses the required scientific concepts and processes needed to participate. In addition, s/he may ask questions, answer questions, and find the answers to the questions s/he has about his daily life (N.R.C., 1996).

Examinations, which are performed in international level, show that students do not achieve a desired degree of success in science. Ünal and Ergin (2006) stress that one of the causes of students’ dislike to science and their failure in science courses is serving scientific information to them without relating the information to their experiences.

New trends in science and technology aim to make students learn actively, saving them from memorizing. One approach for this purpose is ‘writing to learning’ (WTL). Written activities have a great role in success of the students not only in social courses like language and literature, but also in science courses (Yıldırım, Doğanay & Türkoğlu, 2009). Writing is a valuable learning mechanism which enables us to describe, refine, and organize our opinions about a subject and to explore our thoughts, ourselves, and imaginations deeply (Graham, 2008). Writing enhances the thinking capability and makes the brain search for alternatives. In addition, writing becomes a bridge between existing knowledge and new information acquired from in-class discussions and other resources like test books or laboratory exercises (Keys, Hand, Prain & Collins, 1999).

Writing is an approach which has been used in education for thousands of years and consists of both traditional and non-traditional methods. Use of non-traditional methods is quite important for growing thinking and asking individuals (Aybek, 2007). Keys (2000) argued that using writing activities as an inquiry technique contributed significantly to learning. Inquiry research techniques are one of the crucial supporters of science lab (Turkish Ministry of National Education, 2005a). In recent years, one of the
research-inquiry-writing techniques used in laboratory activities is SWH. SWH includes WTL, introduces rich language practices, and aims to teach science via research-inquiry path. Therefore it is an instrument which is recommended to be used in science education (Günel, Memiş & Büyükkasap, 2010). SWH, which is developed in order to enhance learning by writing in laboratory activities by Hand and Wallace, consists of two sections, teacher template and student template (Hand & Keys, 1999). These templates are provided in Table-1 and Table-2.

Table 1. SWH-Student template

1. Beginning ideas – What are my questions?
2. Tests – What did I do?
3. Observations – What did I see?
4. Claims – What can I claim?
5. Evidences – How do I know? Why I am making these claims?
6. Reading – How do my ideas compare with others?
7. Reflection – How have my ideas changes?

Table 2. SWH-Teacher template

1. Exploration of pre-instruction understanding through individual or group concept mapping.
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions.
3. Participation in laboratory activity.
4. Negotiation phase I- writing personal meanings for laboratory activity (For example, writing journals).
5. Negotiation phase II- sharing and comparing data interpretation in small group (For example making a group chart).
6. Negotiation phase III- comparing science ideas to textbooks or other printed recourses (For example, writing group notes in response to focus questions).
7. Negotiation phase IV- individual reflection on writing (For example, creating a presentation such as a poster report for larger audience).
8. Exploration of post instruction understanding through concept mapping.

SWH, which is a writing guide to students and teachers in science, provides both a framework to teachers for activities and a list of cognitive high-level questions for students to ask themselves (Baker, 2004). In this method, students form their research questions, design experiments to answer these questions, develop their hypothesis according to their experiment results, justify their hypothesis with their findings, and defend their hypothesis in discussions. In the end, they reshape their existing knowledge and ideas (Kıoğlu, Erkol, Günel, Gürbüz & Büyükkasap, 2007). Properties of SWH are as follows (Burke, Hand, Poock & Greenbowe, 2005):

- It depends on collaborative effort,
- It supports inquiry-based approach,
- It is technical and directive,
- It teaches students by experiencing,
- It makes students ask themselves what, how, and why questions,
- It enhances conceptual understanding,
- Controls, inputs and outputs are arranged by students,
- It enhances interaction among peers and groups,
- It enables students share their findings both with their group friends and other resources like literature or internet,
• It is totally different from other classical methods that use literature and other resources as they are. SWH is science writing instrument which help students clearly define their opinions, encourage them to take responsibility, and enhance the students’ involvement in the courses (Hand, Wallace & Prain, 2001). It is a method in which all students are active. It also enhances the quality and level of learning (Hohensell & Hand, 2006).

When we make a research in the literature, we see that studies on written activities are increasing in recent years. These studies can be grouped under the title writing to learning (WTL). Results of most of the WTL studies are similar and reveal that this approach contributes to conceptual learning (Hand & Prain, 2002; Hand, Hohelshell & Prain, 2004; Günel, Uzoğlu & Büyükkasap, 2009; Günel, Memiş & Büyükkasap, 2009; Atıla, Günel & Büyükkasap, 2010; Yıldız & Büyükkasap, 2011). It is stated in Hand and Prain (2002) that WTL attracts students and in Günel, Memiş ve Büyükkasap (2010) that it makes the students participate actively in the class. It also enables students express and share scientific information with other students and merges other students’ information with their own (Mason & Boscolo, 2000; Rivard & Straw, 2000; Hand, Hohelshell & Prain 2004). Findings of Akar (2007) which states that WTL enhances student thinking are validated by the studies of other researchers (Mason & Boscolo, 2000; Rivard & Straw, 2000; Hand, Hohelshell & Prain 2004). Writers who participate in WTL activities reshape their information using their existing information (Rivard & Straw 2000; Akar, 2007; Günel, Memiş & Büyükkasap, 2009). In addition, WTL improves commendation ability Günel, Uzoğlu & Büyükkasap, 2009), helps students transform information (Günel, Uzoğlu & Büyükkasap, 2009), and presents information in an organized way (Yıldız & Büyükkasap, 2011).

It is an interesting fact that although there are many researches on WTL, studies on SWH are little in number. In order to understand the nature of SWH, more studies are required. According to the information acquired from existing studies, SWH improves the success rate in science courses (Günel, Memiş & Büyükkasap, 2010; Erkol, Köşoğlu & Büyükkasap, 2010; Erol 2010), builds up a better attitude towards laboratory activities (Erkol, Köşoğlu & Büyükkasap, 2010), and contributes to conceptual learning (Erol, 2010). In this study, opinions of teacher candidates, who used SWH template and traditional laboratory report format in General Physics Laboratory-I course are examined. In addition, opinions of two different groups, one only using SWH and the other using SWH and peer assessment together, are examined.

**Purpose**

The purpose of this study is to examine the views of prospective teachers using SWH template and traditional laboratory report format in General Physics Laboratory-I course. Answers to the following questions were searched during the study:

- What do the teacher candidates think about using SWH or traditional laboratory report in General Physics Laboratory-I course?
- What do the teacher candidates think about using SWH and peer assessment in General Physics Laboratory-I course?
- What do the teacher candidates, who use SWH or traditional laboratory report, think about physics laboratory?

**Method**

This study was performed as the extension of thesis study of Karaca (2011), “Effect of the use of SWH in general physics laboratory-I lesson on teacher candidates’ achievement and scientific process skills’”. Pre-study work performed in Karaca (2011) is summarized below.

Pretest-posttest non-equivalent control group design was used to have a quasi-experimental design. Three groups were randomly selected by the researchers. The teacher candidates of the experimental group performed their laboratory activities using SWH template while the ones of the control group followed the instructions according to the provided an experiment guide. The significant difference between the groups was the instrument used to write reports regarding the laboratory activities. The SWH template was used in experimental group-I and experimental group-II whereas the control group used traditional lab report formats. The teacher candidates performed experiments on nine different subjects during the
The SWH template was evaluated by the researchers according to the rubric. The evaluation results were provided to both experimental groups as feedback for the next course before handling with the experiment. Different from experimental group-I, each pre service teacher within experimental group-II was given a template that another teacher candidate had written (without seeing the researcher’s evaluation score) before the experiment. Each candidate evaluated another teacher candidate’s template using the SWH rubric. After finishing the peer evaluation process, they were given the chance to see both their peers’ evaluations and the researchers’ evaluations. This process in the experimental groups was repeated every week. Thus, the difference between experimental group-I and experimental group-II was the peer evaluation and the examination of the evaluation results by the candidates. The teacher candidates of the control group were given an experiment guide. Nine experiments existed in the experiment guide. Each experiment in the guide were compound of five sections: (1) Name and purpose of the experiment, (2) Tools and equipment to use, (3) Necessary prerequisite/theoretical knowledge, (4) Method of the experiment, (5) Conclusion and calculations. The candidates read what they would do from the guide before coming to the laboratory. They performed the experiments according to the guide and prepared traditional reports to hand to the researchers. The researchers noted missing and incorrect parts of the candidates’ reports, and they were given feedback before the next experiment. Thus, the teacher candidates were aware of their needs (see Karaca 2011 for details).

After the process defined above, semi structured interviews were conducted with random teacher candidates from all groups. In this present study, opinions of teacher candidates about SWH template and traditional laboratory format are presented in the context of information collected via interviews.

**Participants**

90 candidates participated in the laboratory activities during the study. They were the freshmen from Mehmet Akif Ersoy University Education Faculty Department of Science Teaching. All of the participants were enlisted for General Physics-I course. Interviews were conducted with random 32 of them after laboratory activities. Distributions of teacher candidates which form the experiment and control groups according to gender are provided in Table-3.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment Group – I</td>
<td>8</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Experiment Group – II</td>
<td>9</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Control Group</td>
<td>10</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>5</td>
<td>32</td>
</tr>
</tbody>
</table>

**Data collection instrument**

Semi-structured interview form was used as the data collection instrument. The interview form consists of open ended questions which aim to find out the opinions of the participants. Since the applications were different on different groups, interview forms bore small differences. Experiment group-I, experiment group-II, and control group were asked 16, 17, and 11 questions respectively. Interviews were performed individual and recorded.

**Data analysis**

Videos of the interviews are transformed into written data by the researchers. Content of this data is widely analyzed and categorized into main categories, which are determined during data analysis according to similarities and differences. Then, differences among the data from same category are analyzed in order to find out the subcategories. (Yıldırım & Şimşek, 2011). Depending on this application, we can state that data analysis method in this study was content analysis (Weber, 1990). Büyüköztürk, Çakmak, Akgün, Karadeniz and Demirel (2008) defines content analysis as “a systematic and repeatable technique in which some words of a text is summarized by smaller content categories using a code built on specific rules”.
In order to prevent any data loss during transformation process from video to text, researchers watched the videos repeatedly. Then the data was reorganized. This process is “Miles and Huberman Model”, one of the qualitative data analysis models. Punch (2005) states that Miles and Huberman Model consists of three phases: data reduction, data presentation, and shaping the results. Generalizations were made using the acquired results. This is typically encountered ‘grounded theory analysis’. Punch (2005) emphasizes that Miles and Huberman Model provides a useful general view and prepares a good ground for grounded theory analysis. In this context, grounded theory analysis was used together with Miles and Huberman Model during data analysis.

Data and findings

In this section, findings are presented under categories related to research problems in order to keep the research integrity. The categories are; “opinions on SWH student template and traditional lab reports”, “peer assessment”, and “opinions on physics lab course”. Due to the application differences in different groups, there are headers under the categories like ‘experiment group-I’, ‘experiment group-II’, and ‘control group’. Samples from participant statements are also provided alongside the findings. In order to hide the participant identity, codenames were given to the participants. Codenames are totally different from real identities of the participants.

Opinions on SWH student template and traditional lab reports

Experiment group-I and experiment group-II

Teacher candidates in experiment group-I performed their experimental activities according to SWH and wrote their reports. Teacher candidates in experiment group-II performed peer assessment in addition to the activities of the first group. Analysis of the interviews revealed that members of the both groups had similar opinions. Therefore, opinions of these two groups are presented together.

During the interviews, all teacher candidates emphasized that this application contributed to their learning. They stated that performing laboratory activities according to SWH improved their success in physics, helped them understand physics concepts better, and made them understand their deficiencies in physics better. Some samples from teacher candidates’ statements are provided below:

“Reports helped me understand the things we did about the experiment. Because, I considered better things while filling the report. I compared the information. I began to understand the sources of things. That is why it was better.” Hikmet

“I can understand the concepts better and where the formulas originate. Both experiments and the report contributed to it” Hilal

“The way of my expressing me changed and improved with the reports. I can observe myself. From my first experiment report to the last, there is improvement ” Jale

“For example, we could tell ‘we did that’ or ‘we tried that’ while the professor was giving the lecture.” Ceyda

“I managed to understand the concepts completely. Repeating them while writing was beneficial.” Sevil

Most of the teacher candidates agreed that this application contributes to relating physics concepts to daily life. One of them expressed this fact as: “Say we have encountered a simple, ordinary problem in daily life. Now we can generate a solution faster. We just build a relation.... I can find many, countless examples from daily life now. Writing reports contributed to it.”

Candidates stated that SWH applications also contributed them emotionally. They stated that they developed a positive attitude towards physics and their confidence has risen. Samples supporting this fact are provided below:
“I used to be lazy about physics to be honest. I did not like it and I did not want to study it. But now I do. It was very good. It made me like physics.” Ramazan

“I never liked physics frankly. Now I like it more. I began to wonder about physics.” Esra

“For example, I did not know about the slope in plotting. It was very hard for me. Here I learned about slope and I even made calculations on slope. I realized that it was not something so scary.” Sevilay

In addition, some of the participants expressed that they gained discipline in studying. For example, Betül explained her opinion as: “We learned to be more planned, more programmed, and more tidy thanks to the experiment reports. It was for our own benefit when we tried to complete the report on the day we conducted the experiment.”

Control group

The teacher candidates of the control group were given an experiment guide. They performed their experiments according this guide and wrote down their reports in traditional laboratory report format. Analysis of the interviews reveals that they emphasized on meaningful learning similar to the experiment groups. They expressed that writing a laboratory report at the end of the experiments contributed to understanding the concepts and enhanced their success. In addition, they stated that reports helped them to discover their deficiencies. Some sample statements belonging to teacher candidates from control group are provided below:

“We can see everything clearly when we write. We see what sort of a result would happen from the plots. Formerly, when we were in high school, we would ask why we were taught these subjects. Now, we learned the causes by self-experiencing.” Fatih

“The things we did contributed to the physics course. For example, we would not do anything concrete in physics course in high school but now we did. We make the calculations and explain it by proofs. They are now united I think.” Görkem

“We could correct if we had some mistake. We were completing our missing points before we proceeded to the next section. If we did not report, we could not find out our deficiencies and understand the subjects.” Yasemin

“I could build up the relations among concepts easily. Since I have seen proofs in the experiments, I could express myself clearly. I cannot express all scientific information but I can express the ones I have seen in the experiments.” Görkem

In addition to above opinions, one of the teacher expressed that they gained discipline in studying. “It gained me the habit of regular studying. You make the experiment and then you write the report when it is fresh.” Ceren

Peer assessment

Peer assessment was applied only by experiment group-II. All of the teacher candidates have positive opinion towards peer assessment. Participants think that peer assessment enabled them compare their experiment reports with the ones of their friends, they learned how to make assessment during the process, and their success increased thanks to the peer assessment. Some sample statements of teacher candidates are as follows:

“It enabled us compare two papers. Because, say I have some good points, and my friend has some mistakes. It helped us compare and correct the missing points. Of course it made me happy to see the reports of my friends.” Hikmet

“We were making assessment. In the future, when I become a teacher, will I be able to act objectively? Will I assess the paper according to the writer? Thinking from another perspective, I focused directly on some information and noticed that I could do the assessment really objectively. I improved myself in assessment.” Özlem

“I saw the differences between my paper and the one of my friend. My grades improved that way. I cared more on my missing points.” Ümit
Opinions on physics lab course

Experimental group-I and experimental group-II

Most of the interviewed teacher candidates stated their positive opinions about physics course. Participants emphasized that their success in the course improved, writing about psychics made them think of physic concepts, their knowledge got stronger while writing, and retention of their knowledge improved. Sample participant statements are as follows:

“Filling experiment reports made us express our knowledge in an organized way. Comparing our pre-test opinions and post-test opinions improved our commendation.” Ayşen

“Running the physics laboratory course this was nice. It is obvious that our knowledge improved. It has many advantages both about the experiment and for our future teaching career.” Rabia

“If we did not dig so deep in detail, we could not understand the subject to this extent.” Tuğçe

“Writing a detailed report every week after the experiment helped me to learn the subject better.” Ramazan

Some of the teacher candidates thought that writing reports using SWH template was hard and boring. Teacher candidates say that this was because of the detail level of SWH template and preparation of the report took too much time.

Teacher candidates divided into two groups, one preferring to design their own experiments and the other preferring to perform verification experiments on designed experiment templates, when they were asked what sort of experiments they prefer to conduct in physics laboratory. Sample supporting statements for both ideas are as follows:

“I would like to design my own experiment. I learn more that way.” Neriman

“I think following an experiment guide is better. It is hard to design an experiment on my own.” Lamia

“For sure we would be more confident if we performed our own experiments.” Gözde

“When we conduct the experiment according to an experiment guide, we know what we do and why we do. So that our knowledge becomes more retentive.” Murat

Most of the teacher candidates expressed that they would like to perform the laboratory activities in as group activities. Only a few of them stated that they would prefer individual study. Sample supporting statements for both ideas are as follows:

“I would definitely conduct the experiments in group. Ideas of my friends are very effective on the experiments. Since every of them have another idea, we shape and perform the experiment far much easier.” Ayşen

“I would like it individual. Because it would make us more confident. Since we will be teachers, we would learn more.” Ceyda

“I would like to perform it in a group because I might have a mistake and a friend of mine would warn about it.” Hikmet

“I do not like doing things as a group because everyone does not put the same attention.” Tuğçe

Control group

Teacher candidates generally prefer learning physics concepts in laboratory during experiments to theoretical physics courses. In this context, they have positive attitude towards laboratory. As an example, Fatih thinks; “Physics laboratory course is very entertaining. I understood the concepts and this was fairly good for education. Since it was visual it was very easy to learn. Laboratory courses are not like other courses. It is better.”

In the interview, after a briefing about SWH template, control group candidates were asked they would like to use traditional laboratory report or SWH template while writing their physics experiment reports. Most of the candidates of control group preferred writing in detail similar to SWH template. Some of the teacher
candidates thought it was hard to write in SWH template because it involved many details therefore they selected traditional laboratory report format. Sample supporting statements for both ideas are as follows:

“Using SWH template in laboratory would be better in means of expressing ourselves indeed. It would be better especially realizing physics concepts in daily life and making comparisons.” Merve

“In my opinion, it was better this way. It is easier this way so I would prefer this. We have trouble in making comments. I know the subject but I cannot unite things in my head.” Yasemin

When the teacher candidates were asked how they would like to perform their experiments in physics laboratory, some preferred to design the experiments of their own and some preferred to make experiments following an experiment manual. Sample supporting participant statements for both ideas are as provided below:

“I would spend more effort for designing my own experiment but I would do it.” Akasya

“I would not design my own experiment. I have tried it before. It is too complicated. Nothing can be understood this way.” Ayşegül

Half of the members of the control group would like to conduct experiments as a group while the other half preferred individual experiments or stated that depending on the experiment, they would participate in a group. Some sample statements about this fact are provided below:

“Conducting the experiments as a group is better because when you have some trouble understanding our friends say ‘no it is not like that, it is like this’. Alone, we may have some mistakes.” Özge

“It would be better if we did something individual.” Ayşegül

“There are experiments to be done as a group and there are experiments to be done individually.” Selin

**Discussion and conclusions**

Research results indicate that teacher candidates, both conducting experiments according to the SWH template and conducting experiments according to traditional laboratory report format, have similar opinions. For both applications, teacher candidates think that lab activities and writing reports help them achieve meaningful learning, make them study with discipline, make them be aware of their deficiencies and mistakes, and improve their success in physics course. In this context, both traditional laboratory report and SWH template are found to be supporting the understanding by all participants. This is also stressed in previous studies (Karaca, Uluçınar & Cansaran, 2006; Günel, Memiş & Büyükkasap, 2010). In addition, participants who used SWH template stated that they were able to transfer their knowledge of physics to daily life better, they grew a positive attitude towards physics (Günel, Memiş & Büyükkasap, 2010; Erkol, Kışoğlu & Büyükkasap, 2010), they gained more confidence, and they expressed themselves better. This finding supports the fact that SWH template encourages the students think actively by directing them to research and question and write in detail.

All of the interviewed participants have a positive opinion about peer assessment. Participants state that comparing their reports to their friends, they learned how to evaluate and comparisons improved their success in the course. Candidates’ opinions do not reflect a clear difference between the only SWH applied group and the group which applied peer assessment with SWH. It is possible that SWH using group might have focused on application more than assessment. Participants, who made peer assessment, dealt with how peer assessment is performed as well as the contribution of peer assessment. Some of the participants considered peer assessment contributive to their improvement about assessment of students as future teachers. In addition, since the participants are teacher candidates, they might have a critical perspective to the application while peer assessment process. Teacher candidates also emphasized that writing while doing peer assessment contributed to their success. This fact is similar to the findings of Karaca (2011).

Generally, attitude of the participants, both using SWH template and traditional laboratory report, towards the physics laboratory course are positive. They stated that writing reports made them think about physics concepts, contributed them for retention of their knowledge, and strengthened their learning.
All of the participants who used SWH template in the laboratory course stated that they would like to conduct experiments as groups where only a half of the participants who used traditional laboratory report preferred group work. These opinions are quite important since they support the fact that SWH encourages group study. Some of the teacher candidates think that writing laboratory reports according to SWH template in the course is boring or hard at all. They think so because the SWH template is detailed and time consuming for them.

A general evaluation of the opinions of the teacher candidates indicated that they were willing to understand and learn physics concepts in the laboratory by conducting experiments. They think that writing reports for physics laboratory course contributed them from many aspects. Researchers think that the reason for the absence of significant differences between the opinions of three different groups is they all realized the activities by their own experiments. All of the candidates stated that they had never conducted science lessons in a laboratory environment depending on observation and experiments during their elementary and secondary school careers. Therefore, this fact made the researchers think that the participants focused on performing laboratory activities rather than the differences between report writing approaches applied by different groups. This study was conducted in General Physics Laboratory-I course of freshmen teacher candidates. Studies on different laboratory courses with different grades might provide us more information on the nature of use if SWH template.

References


*Proceedings of The World Conference on Physics Education 2012*
WCPE 2012 Curriculum Symposium:
Introduction to the contributions from five countries

Maarten Pieters, Netherlands Institute for Curriculum Development SLO
m.pieters@slo.nl

On 3 July 2012, the morning’s program symposium was dedicated to secondary education physics curricula in five countries: Brazil, Korea, the Netherlands, Turkey and the USA. The contributions highlighted the following items:

1. characteristics of secondary education physics curricula
2. their relation with economic and political motives, and with educational research
3. the way curriculum development is organized and how that influences modernization of the curriculum

In the following, the contributors give written accounts of their oral presentations, with some aspects elaborated more than what had been possible during the symposium. Their focuses differ, but in particular on the first two items mentioned above we see strong similarities, in spite of differences in curriculum organization and responsibility.

As for responsibilities, top down curriculum development seems to favor political motives more than motives from research, as the articles presented here suggest. Good ranking in international comparisons is mentioned a few times as motive, it may be getting crowded at the top. Another, interesting point is that the social aim of equity coincides with the economic purpose of mobilizing as much science and engineering talent as possible: the enrollment of female students and members of ethnic minorities is to be increased.

When we look at the curriculum content, we see a strand of combining physics concepts with science, technology and everyday life applications (contexts) in curricula. The same goes for combining conceptual knowledge with strategic skills or competencies, cross-cutting the physics topics – for the new Turkish curriculum this combination is the very heart of the matter. A few highlights: the Turkish curriculum distinguishes Physics-Society-Technology-Environment skills, Informatics and Communication skills and Attitudes and Values. The São Paulo curriculum assigns a strategic emphasis to modeling processes, the use of experiments with low cost material and the use of historical approaches. The Dutch program crossbreeds content areas with research activities, design activities and modeling activities. The Korean physics I curriculum connects inquiry activities with an understanding of the nature of science. The US Next Generation Science Standards include practices such as ‘developing and using models’ and ‘constructing explanations/designing solutions.’

Modern physics (quantum physics, relativity, cosmology) is present in all described curricula, in some of the countries this is new compared to their previous curriculum.

Conceptual physics draws attention in some ways. The Dutch curriculum aims at reducing the role of ‘picking the right formula, followed by mathematical routine’ in favor of a more conceptual understanding of physics’ models. The new emphasis is evaluated as possibly more difficult than the formula routine, in particular for students from the Science and health stream, the most popular among female students. In the USA, students have relatively much freedom of choosing physics courses from a varied collection. Statistics show that in the USA, female students are well represented in conceptual physics courses and less to much less in advanced placement courses. US colleague Jacqueline Spears writes about this: ‘Given that these [latter] courses provide better preparation for required university physics courses and can enable students to earn college credit for those courses, the lower participation of women is thought to contribute to the lower numbers of women enrolled in engineering, science, and mathematics programs at the university level.’ It seems that the term conceptual physics can represent a curriculum that is not mathematical enough for qualifying for engineering, science and mathematics in higher education. While at the same time it can mean a more difficult curriculum than a mathematics oriented one. Apparently, much depends on the role mathematics plays in the architecture of the physics curriculum at both the school and university level.

There is no lack of challenges. Countries or states with one physics course for all face the challenge: how to combine physics as general education with physics as a preparation for future science and engineering students?

For more information, motives and challenges, we now invite you to go deeper into the following five countries’ accounts on physics curriculum development.
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New Physics Curriculum for Secondary School: The Case of São Paulo’ State

Maurício Pietrocola, Faculty of Education - University of São Paulo
mpietro@usp.br

Introduction

Curricular changes are surrounded by dilemmas, doubts and difficulties - not only because of their complexity, but especially because of societal expectations. The values, behaviors and trajectories in societies are sources of educational requirements. Changes in society inevitably require new curricula. In these situations, schools, and particularly teachers, are asked to review their practices and modify their practices.

In Brazil, a little more than 15 years ago, there was a situation like this. In 1996, the Basic Law of Education (LDB) outlined needed changes in basic and professional education. This document made clear the challenges created by new technologies, which clearly influence the modes of production, value and processing of information. Published in 1998, the National Curriculum Parameters (PCN) were a result of this pressure for change and, in turn, had an impact on the curriculum and organizational structure of education systems across the country.

Science curricula, more than other areas of school curricula, are resistant to external pressures for change. External influences originating from the larger educational system increase the burden of change made by the internal demands specific to science. First, scientific knowledge is in constant evolution and transformation. This implies that, from time to time, there is a need to revise the science content to be taught. Secondly, because there are questions arising from the lack of intrinsic efficiency in the process of teaching and learning, science teachers are constantly alert to the success of the teaching practice. They care about the students’ motivation and interest in science as well as the relevance and usefulness of the science content. Historically a large number of initiatives resulted in significant science curricular reforms. The 1960s, for example, became known as the “era of the projects,” encompassing curricular projects such as PSSC, BSCS, PILOT UNESCO, etc. More recent projects aim to introduce and evaluate the impact of science curricular innovations in content, methodology, and/or the organization of teaching and learning.

Particularities of Curriculum Development in Brazilian Secondary Education

Brazil is a federative country, which means that we have a central (federal) government and 27 states. States range from those that are dominated by large cities such as São Paulo (more then 15 million of habitants) to those that serve communities of less than a thousand inhabitants.

The educational system is regulated by these three levels – federal, state and city. The table below provides an overview of the responsibilities of each administrative level.

Table 1

<table>
<thead>
<tr>
<th>Level</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental education</td>
<td>in charge by city administration</td>
</tr>
<tr>
<td>Middle education</td>
<td>in charge by state administration</td>
</tr>
<tr>
<td>Secondary education</td>
<td>in charge by federal administration (not so strict)</td>
</tr>
</tbody>
</table>

Secondary education is mostly managed by the individual states, which vary significantly. In terms of climate, economic development and culture. From south to north, climate varies from hot to temperate; economic development ranges from highly developed to under developed; and culture varies from those with Indian/African roots to those with predominantly European roots. These differences have resulted in more locally defined educational programs. Instead of a national or state curriculum, Brazil establishes Parameters and Propositions for the curricula that, in turn, guide the curriculum used in the schools.
In 1998, the National Council of Education published a National Curriculum Parameter (PCN) based in the LDB of 1996. It included a general set of goals and rules about the way schools were to operate. PCN was designed to induce states to review their own curricula. Although there is a very new system of national assessment (output regulation) offered to all students finishing the last year of secondary education, use of this system is not mandatory. It means that each state has its own specific goals and rules. These two levels of regulations (federal and state) do not affect the way teachers plan their curricula or give their lessons. Publishers are free to publish any content that meets the attainment targets. Teachers are free to choose the books they prefer or use their own material.

In the State of São Paulo, the Secretary of Education initiated revision of the school curriculum in 2007/2008. The particular motivation for the new curriculum in São Paul was a decrease in students’ performance on national assessment exams. The process didn’t officially involve the universities, which are the center of educational research. Instead the Secretary of Education appealed to individual specialists, chosen by reputation and proximity to the administrative system. Some came from universities and others from the educational system itself (experienced teachers, principals, technicians, etc.). The process was organized through working groups established by disciplinary specialization. At the secondary education level, science is divided in three main branches: biology, physics and chemistry. Each group defined its own goals and principles. It is important to note that São Paulo’s curriculum, as in most of the other states, serves all students regardless of their future career plans. This means that the physics, biology and chemistry programs were organized to prepare people for life in Brazil’s larger society.

The physics working group was composed of physics education researchers and high school teachers. It was decided to follow the goals and proposition present in the federal parameters (PCN). Given that the teachers were aware of the goals and propositions outlined in the PCN and that this document met the expectations for a new secondary physics, the physics working group relied heavily on the PCN. The main goal was to prepare students to be critical thinkers, able to use science knowledge to reflect and solve problems in everyday life. The physics curriculum proposed included a document describing the importance of physics knowledge, the primary goals in the teaching and learning of physics at secondary level, guides for teachers and workbooks for students.

The new physics curriculum was based on three guiding principles that address limitations seen in the traditional program. These are that physics at the secondary level must be presented:

- in view of its historical development, not only in terms of conceptual exploration or use of equations. This will strengthen the value and meaning of physics content in classroom.
- in ways that make clear the connections between physics and the needs and challenges of modern society. This will arouse the interest and motivation of the learners.
- using physical phenomena as challenges for thought. This summons the imagination to overcome, increasing the pleasure of learning and a taste for science.

The physics curriculum has been updated in an effort to align it more closely with the contributions made by physics education specialists in the working group.

The curriculum development process took two years. Most of the time was spent in developing the teacher guides and student workbooks. Twelve guides (four for each grade) were developed for teachers and twelve workbooks (four for each grade) were developed for students. The materials were revised in 2009, after pilot testing by teachers and students in 2008. Modifications were made to the text, figures, and tables.

**Characteristics of the New Curriculum**

In contrast to the old curriculum organized by concepts, the new curriculum is based on thematic perspectives. For the most part, the physics content is presented in a social/technological context. The major shifts from the curriculum used prior to 2007 to that being used today are:
Grade 10

Old: Kinematics: Newton's Laws, Mechanical Energy
New: Movements: Variations and Conservations; Universe, Earth, and Life

Grade 11

Old: Thermometry: exchange of heat; engines; Geometrical optics; Mechanical waves
New: Heat, Environment and Uses of Energy; Sound, Images, and Communication

Grade 12

Old: Electrostatics; Electrical Conductor and Insulator, Electric and Magnetic Fields, Electromagnetic Induction
New: Electrical Equipment; Matter and Radiation (Modern Physics)

The intention was not to change the curricular content in an abrupt way! It was expected that teachers could recognize the new curriculum as an evolution of the older curriculum. The exception was the proposition to teach some topics in modern physics (physics from the 20th century). The new program also emphasizes the modeling process, the use of experiments conducted with low cost materials, and the use of an historical approach. Another important shift was in the definition of the learning objectives: from the content to competences. A list of competences was developed for each two-month module in grades 10-12. Each competency was described in a single sentence no longer than two lines.

Dilemmas, Conflicts, Perspectives

After finishing the process of curriculum development, we, as researchers in physics education, perceive some challenges that must be faced in the future:

- How to prepare students for scientific careers separately from those pursuing non-scientific careers? (For example, Brazil needs at least 50,000 engineers in the next 10 years.)
- How to deal with the combination of conceptual themes and social/technological contexts, both part of the new curriculum?
- How to balance the general education needed for life in society with the technical education needed by industry?
- How to improve the number of secondary school physics teachers? (Actually, there is a shortage of more than 5,000 physics teachers in the state of São Paulo alone! It is not an attractive career: low salary, hard work.)
- How to prepare teachers to teach in a new way? (Some physics teachers lack the competency to teach modern physics, to use an historical approach, etc.)
- How to increase of public budget for education?
- How to increase teacher education programs and faculties to prepare physics teachers?
- Which programs could fixed physics teachers in pre-service courses?
- How to implement the full-time school?
A new physics curriculum in The Netherlands: characteristics and development

Maarten Pieters, Netherlands Institute for Curriculum Development SLO, m.pieters@slo.nl

Abstract

In 2005, a 5 year project started in The Netherlands, developing a new physics examination program for senior high school. The Minister of Education instituted a committee with the assignment of advising her on a new program. After a three year pilot, a program was advised to the Minister in 2011. It was accepted with some technical adjustments, and will be effective in 2013. Its first exams will be held in 2015. Both the curriculum itself and the design of its development project were influenced by results from research on science education and on curriculum development. Formative evaluation played a dominant role in the process of development.

1. Initiative for new science curricula

In 2004/2005, the development started of new examination programs for upper secondary curricula (ages appr. 15-18 year) in biology, physics, chemistry and mathematics; and in a new optional subject, Nature, Life and Technology (NLT), going deeper into the matter and connecting various disciplines’ approaches. The programs were to give young people a stronger feeling for the relevance of science, raising their interest for a career in science. Programs were developed for two school types: senior general education (havo – 25% of all secondary education matriculants) and pre-university education (vwo – 19%). Both havo and vwo know a science and technology and a science and health stream; they differ only in compulsory subjects – subjects’ content does not differ between streams. Physics is compulsory only in the science and technology stream, but most science and health vwo-students take it because it gives access to a medical study.

The assignments for all curriculum committees were guided by the following aims:

1. increased actuality and relevance of the secondary science curricula
2. use of science concepts in contexts from the worlds of research, professions and everyday life
3. more coherence within and across the science curricula
4. better fit in the available time.

In the following, the characteristics of the new curriculum (section 2) are described, as well as its development in a pilot (section 3), in particular the roles of the various stakeholders. Both for the curriculum and for its development process some connections with recommendations from research will be given.

Some data on The Netherlands and education

sourcess: Statistics Netherlands (CBS), Ministry of Education (2012), VHTO, World Bank data (WB)

<table>
<thead>
<tr>
<th>Source</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total population (2011, CBS)</td>
<td>16.7 million</td>
</tr>
<tr>
<td>GDP per capita (2010, WB)</td>
<td>USD 50 076 / EUR 37 557</td>
</tr>
<tr>
<td>Public spending (2011, CBS)</td>
<td>EUR 300 billion, 50% of GNP</td>
</tr>
<tr>
<td>Public spending on education (2011, MoE)</td>
<td>EUR 30.4 billion, 5% of GNP</td>
</tr>
<tr>
<td>Public spending on secondary education (2011, MoE)</td>
<td>EUR 7.1 billion</td>
</tr>
<tr>
<td>Private spending on secondary education (2011, CBS)</td>
<td>EUR 1.50 billion</td>
</tr>
<tr>
<td>Number of secondary education students (2011/2012, CBS)</td>
<td>948 949</td>
</tr>
</tbody>
</table>

1 http://betavak-nlt.nl/English/
2 http://www.cbs.nl/en-GB/menu/organisatie/default.htm
4 http://data.worldbank.org/
Distribution of all students in the first upper secondary year over the various streams in 2011-2012 (source VHTO)

<table>
<thead>
<tr>
<th>school type</th>
<th>havo (senior general)</th>
<th>vwo (pre-university)</th>
</tr>
</thead>
<tbody>
<tr>
<td>science and technology</td>
<td>16 %</td>
<td>33 %</td>
</tr>
<tr>
<td>science and health</td>
<td>19 %</td>
<td>23 %</td>
</tr>
<tr>
<td>economics and society</td>
<td>48 %</td>
<td>35 %</td>
</tr>
<tr>
<td>culture and society</td>
<td>16 %</td>
<td>9 %</td>
</tr>
</tbody>
</table>

Distribution of female students (as percentages of all female students) in the first upper secondary year over the various streams in 2011-2012 (source VHTO); in the period 2007-2011, female students form an almost constant fraction of all students of about 50% for havo and about 54% for vwo.

<table>
<thead>
<tr>
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<th>havo (senior general)</th>
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</tr>
<tr>
<td>culture and society</td>
<td>16 %</td>
<td>9 %</td>
</tr>
</tbody>
</table>

Explanation:
- students who combine both science streams are included in the row “science and technology”
- percentages in both tables do not show significant trends during the years 2007-2011, with the exception of a slight increase of the economics stream, at the cost of the culture stream.

Particularities of curriculum development in Dutch secondary education

In senior secondary education, The Netherlands knows input regulation in the form of goals and rules about the way they are assessed (output regulation) (Nieveen & Kuiper, 2012). Teachers are free in planning their curricula and shaping their lessons. Publishers are free to publish any content that meets the attainment targets, teachers can choose the books they prefer, or use their own material. These characteristics limit government’s possibilities to influence the quality of senior secondary education – even more so in primary and lower secondary education.

For a curriculum development project in senior secondary education this means that
- national prescriptions are only made as globally formulated attainment targets, further detailed in syllabus specifications for the 60% content to be assessed in national examinations
- the “how” of education is the responsibility of schools and teachers; most schools outsource the curriculum planning to the textbooks, which in turn don’t need any approval other than market demand.

National assessment replaces entrance exams of higher education. Students choose a stream with compulsory and optional subjects. Their choice limits the studies to which they are admitted.
2. Characteristics of the new curriculum

2.1 Domains of concepts and contexts

As for the new physics program, the major shifts compared to the current one are:

• more emphasis than before on the conceptual nature of physics, less on ‘picking the right formulas’

• more stress on science practice consisting of research, design and modeling activities – a shared focus with the other new science programs

• students should be able to use all mentioned physics concepts in contexts; some context areas are explicitly mentioned as part of the content: medical imaging, human body, and earth; for the pre-university variant also astrophysics and biophysics

• the pre-university stream will contain quantum physics and, as optional subject matter, special relativity.

Core physics concepts remain at the heart of the curriculum, contexts serve as their legitimation and for making students practice the wide usability of scientific concepts, in various contexts. Some contexts are prescribed explicitly, in those cases they are seen as part of the senior secondary physics curriculum, giving a view on actual physicists’ practices.

The new examination program consists of the following elements.

domains of competencies

• general competencies, identical for all subjects, e.g. information processing and communication

• science and technology competencies, in particular research, design and modeling

• physics competencies, among which mathematical skills and computer use in modeling and data processing

domains of concepts and contexts

for senior general education

• information transfer

• medical imaging

• motion and energy

• materials

• earth, solar system and universe

• human body

• measurement and control

• physics and technology

for pre-university education

• information transfer

• medical imaging

• motion and energy

• charge and field

• radiation and matter

• quantum world and relativity

• life and earth

• laws and models of nature

Each of these domains is described with maximum two attainment targets. The domains are specified in terms of physics concepts and mastery levels. Some subdomains are assessed in a national assessment, these are further specified.

2.2 Influences of society’s desires on the curriculum

The new program reflects an increased emphasis on the actual practice of physics researchers and technologists, and its relevance. Thus, it responds to society’s request to address the decline in young people’s interest in science and technology careers in the high school curriculum, among others. In The Netherlands, this interest is relatively low compared to other countries (OECD, 2007; Cito, 2007).
Government policy also asks for a top-5 position in PISA and TIMMS rankings concerning science. The new program has been designed with the purpose of facilitating, within time and system constraints, the best possible physics education: effective, efficient, motivating, without hiding physics’ difficulty (Van Weert, 2007). No teacher or curriculum designer will regret a high ranking position as emerging from good education, but the ranking has not been a purpose in itself (compare Sahlberg, 2011, on the success of Finnish education).

2.3 Influences of research results on the curriculum and its development

The assignments for the science curriculum committees express the results of studies into young people’s interest in science (e.g. OECD, 2007). Also, teachers’ satisfaction with existing curricula had been assessed (SLO, 2002, 2003, 2006), leading to the desire for more coherence between the subjects and for less time stress.

The new physics program has taken into account that learning is facilitated by learning to use concepts in more than one context, which stimulates the construction of scientific language (Driver et al., 1994), and by the use of meaningful contexts (Bulte et al., 2006). The attainment targets state that given physics concepts should be known and used in contexts.

Sufficient time is crucial for learning as developing understanding rather that memorizing (Bransford et al. 2010, Ch. 3). The hours for senior secondary physics education were reduced in the past 30 years by almost half. Consequently, the time per concept or domain could only be saved by reducing the number of concepts or domains: “less is more”. New content, such as quantum physics or physics of the human body, was introduced; more goals regarding research, design and modeling competences were introduced. Inevitably, some old darlings had to be killed; examples are geometrical optics, signal processing, nuclear chain reactions in a reactor.

2.4 Evaluation during the pilot

The pilot curriculum was evaluated by two groups: the committee itself and the department of research of the Netherlands Institute for Curriculum Development (SLO).

The committee’s evaluation was a formative evaluation, leading to a validated advise to the Ministry. See the upward arrows in Figure 1. SLO’s evaluation (Kuiper et al, 2011) was committed by the Ministry as an independent evaluation, involving all science curriculum projects running at the time. It examined to what extent the renewals have met the intended principles and have resulted in executable programs. These evaluations make that the new program can be called evidence informed. Their main conclusions were the following.

Components of the new programs that did well in the pilot were:

- attention to contemporary practice of physics, by using concepts in contexts offering a view on those practices
- attention to the coherence of physics with other science disciplines
- combining broadness for all pupils (science literacy) with depth for those who opt for a career in science
- the possibility for teachers to teach with pleasure.

On three of the committee’s aims, too little benefit was found in the evaluations of the first cohorts:

- fit in the available time
- attention to practical work
- more enthusiasm of girls for physics.

These conclusions could be used in the final adjustments.

Problems with time and practical work were connected: teachers solved a lack of time by reducing practical work. In a second round – which could not be completed in the project’s years – some of the problems were solved. Concerns remained and gave rise to partial revisions in a third design, which was included in the final advise to the Ministry of Education.
The committee’s lack of success in making a difference in girls’ enthusiasm over the whole of pilot schools – although some individual teachers did mention a significant shift – suggests that attainment targets on their own cannot make the difference.

3. Characteristics of the curriculum development process

3.1 The pilot

The physics curriculum committee consisted of teachers from secondary education and higher education, researchers and an industry representative, and was supported by a project team. It organized a pilot in 2007-2010 (see figure 1). Prior to the pilot, a strategic vision was formulated in consultation with the field (2005), a first draft program was designed (2006) and first teaching materials were written (2006 and onward).

Figure 1: The pilot process for the new examination program and the interconnectivity of activities, with time line at the left hand side. The years at the right hand side present the delivery of the formal advise to the Ministry and the planned syllabus.

Upscaling the new program for national use, with activities from 2011 on, is supported by products from the pilot project, in particular: teaching materials, the syllabus, exam tasks for the pilot students’ national assessment, the revised examination program and the final reports with evaluations and recommendations.

Apart from these products, the project has also yielded experiences of people. For upscaling of the programs to national level, these people are crucial, as well as their experiences, their organizations and their connectedness in networks. A few important examples:

- quite some authors of pilot teaching materials – all of them teachers – have been recruited as authors, by publishers and by centers for teacher professionalization
- pilot teachers are sources for non-pilot teachers; some have been recruited as authors or for a coaching role in professionalization
- developers of national exams for the pilot will remain involved as developers
- regional science education support centers will support teachers’ professionalization, ongoing curriculum development and co-operation between secondary and higher education.
3.3 Research results and the curriculum development process

There is ample evidence that the success of implementation of an innovation depends largely on the professionalism and engagement of teachers (Fullan, 2009; Loucks-Horsley & Matsumoto, 1999; Van Veen et al., 2010). Their professionalism is crucial in the innovativeness of the system, its capacity to engage in continuous improvement, which is to be distinguished from an innovation offered to the system (Fullan, 2009). The curriculum development process described here aimed at nourishing and securing an organization that can support science teachers’ professional development. This organization consists of a wide range of stakeholders (Nieveen et al., 2010). There are no single cause-effect relations between the initial ideas of a curriculum innovation at political level, their execution by teachers and their learning by students.

The development process involved the following groups of stakeholders:

- policy makers:
  - Ministry of Education
  - Committee for the Renewal of Senior Secondary Physics Education
- examination agencies
  - Institute for Educational Measurement (Cito)
  - Examination Board (CvE)
- interest groups
  - Dutch Association of Science Teachers (NVON)
  - Dutch Physical Society (NNV)
  - National Platform Science & Technology
- schools
  - pilot teachers (about 35, approximately 3% of upper secondary physics teachers)
  - authors of pilot teaching materials (approximately 10)
  - all teachers, in consultations and discussions (several dozens were active, an estimated number of several hundreds kept themselves informed)
- teacher education
  - regional support centers
  - some members of the Committee for the Renewal of Senior Secondary Physics Education
- publishers
- expertise centers
  - Netherlands Institute for Curriculum Development (SLO)
- support agencies
  - regional support centers

The inspectorate was not involved, it has no task in subject-related judgments. School leaders other than those of the pilot schools have been involved – through their professional organization – since the start of the upscaling activities in 2011.
In 2010, SLO published an implementation plan for the new science curricula, designed in close consultation with the curriculum committees and the other stakeholders mentioned above (Michels, 2010). The implementation is rooted in several fields, among which the following strands:

- (further) subject development
- teacher development
- school development.

The 10 support centers for science education are regional cooperations of universities, professional colleges and secondary schools. They play a key role in these strands. A joint effort of the regional centers and national stakeholders from education and from the physics community is now aiming at their consolidation. If this is successful, the innovation of science curricula will have increased the innovativeness of the science education community. In the end, that will be a more sustainable success than “just a new curriculum”.

**Sources on the web**

www.betanova.nl with documentation about all science curriculum innovations

www.betasteunpunten.nl about regional support centers for science education

**Literature**


Van Weert (2007). *Makkelijker kunnen we het niet maken, wel leuker. Reflecties over onderwijs en leren van de natuurvakken en wiskunde*. [Easier we can’t make it, but more pleasant we can. Reflections on teaching and learning science and mathematics.] Amsterdam: Universiteit van Amsterdam.
The Renewed National High School Physics Curriculum in Turkey

Uygar Kanlı, Gazi University, Gazi Faculty of Education, Physics Education Program, Ankara, Turkey
(Served as a member of Physics Curriculum Committee)
ukanli@gazi.edu.tr

Abstract

The section of this study is to explain how the Turkish National High School Physics Curriculum was designed and developed. The curriculum reform in Turkey started at primary school curricula in 2004. This reform was extended to secondary education. The curricula for grades from 1 to 8 were completed and implemented in a step by step way since 2005. Inevitably, high school physics and other science subjects had to follow the new science and technology curriculum and build on top of where students left at grade eight. The physics curriculum development effort begun in January 2006. The new physics curriculum for grade 9 was developed and begun to be implemented first in school year 2008-2009. Then other grades curricula were implemented in every consecutive year.

1. Initiative for new science curricula

Turkey has a population of 74 million. The Ministry of National Education (MONE) is responsible for pre-primary, primary and secondary education in Turkey. The twelve years primary and secondary education are compulsory for all and provided for free in public schools. According to the statistics by the Ministry there are about 16 905 143 million students and 774 602 teachers at the primary and secondary education levels (MONE, 2011).

Children who have not yet reached formal school age may attend preschool. Preschool education is not compulsory. There are 1 169 556 students attending preschool during school year 2011-2012. Children ranging in age from 60-months-old to 12 years are obliged to attend primary and secondary school. Primary education divides into 4+4. There are 10 979 301 students attending primary school during 2011-2012. Secondary school consists of four years and it is compulsory. It covers science, Anatolian and vocational technical high schools. There are 4 756 286 students attending secondary school during 2011-2012 school year. At the end of high school, following the 12th grade, students have to take and pass the university entrance exam to continue their studies at a university. The physics course starts at grade 9. After grade 9, students who will prefer to study in science fields at university continue taking physics course. Before grade 9, there are physics units in the Science and Technology Curriculum, from grade 4 to 8.

The primary and secondary school curriculum reforms started in Turkey in 2004. One important factor to develop a new curriculum in Turkey was the fairly pessimistic position in international assessment programs including PISA, TIMMS and PIRLS. Another major factor is the overall reformist tendency observed in the government policies to facilitate accession to the EU.

In 2004, the renewed primary science and technology curriculum has seven learning areas with four content strands (Physical Processes, Life and Living Beings, Matter and Change, The Earth and the Universe) and supported by skills (Science Process Skills, Science-Technology-Society-Environment, Attitudes and Values). There is a spiral approach for each strand; mainly based on the constructivist approach; enriched with teaching activities and multiple assessment methods and techniques.

2. Characteristics of Physics Curriculum in Turkey

2.1 Domains of concepts and contexts

The vision of the new physics curriculum in Turkey is to educate individuals who have internalized physics as meaningful in real-life. Missions of the curriculum are a real-life context based approach, outcomes in terms of skills and in terms of content (Ateş et al. 2009)
The physics curriculum emphasizes that:

- learning is a mental process and students learn best by actively involving in this process both mentally and physically
- assessment is not a distinct process from teaching and learning
- performance/authentic assessment can be emphasized
- every student can have misconceptions about physics concepts,
- one of the most important factors affecting student achievement is what students bring to the physics classes,
- the teachers and the authors teachers should be aware of students’ misconceptions about physics subjects,
- instructional methods in physics class focus on a real-life context based approach,
- skills (PSS, PSTE, ICT, and AV) are the main part of the contents, therefore skills should be emphasized as well as contents of physics

The Physics curriculum is mainly based on two learning strands; content knowledge and skills. The skills and content knowledge are not independent from each other. Objectives of skills were interwoven into content knowledge objectives (Serin and Kanlı, 2008).

**Content knowledge**

The Physics curriculum has a spiral structure. Content knowledge is given spirally in every year. As some units are given in every year: Properties of Matter, Force and Motion, Electricity and Magnetism, and Waves. The units Nature of physics, Energy, Modern Physics, Quasars and Quarks are given only in some years. Special attention is given to the 9th grade physics curriculum, compared with the following grade levels, since all high school students will have to take the 9th grade physics course and after this grade some of them will not take any physics courses any more. For this reason, physics topics that all students may face in their life were incorporated into the 9th grade course. In the curricula, it is suggested that physics topics necessary for everybody are tried to be given in a contextual approach in this grade. Physics topics considered to be essential will be given in a conceptual framework as convenient as possible by taking into account spiral curriculum and context based approaches in 10th, 11th, and 12th grade levels. The content of grades physics courses is given in Table 1.

### National Physics Curriculum in Turkey

<table>
<thead>
<tr>
<th>GRADE</th>
<th>Nature of Physics</th>
<th>Energy</th>
<th>Force and Motion</th>
<th>Electricity and Magnetism</th>
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</table>

**Skills**

Skills are collected in four domains. These are:
- problem solving skills (PSS),
- physics-society-technology-environment (PSTE),
- informatics and communication skills (ICS), and
- attitudes and values (AV).
**Problem Solving Skills (PSS)**

PSS include scientific process skills, creative thinking skills, critical thinking skills, analytical and spatial thinking skills, data handling and computational operations, and higher order thinking skills. A systematic approach was presented in solving a problem by integrating these skills together. Three general objectives stated for these skills are as follows:

Students should be able to:

- Identify a problem to be investigated and make a plan to solve this problem.
- Make an experiment to solve the problem identified and collect data.
- Handle data obtained to solve the problem and interpret them.

**Physics-Society-Technology-Environment (PSTE)**

PSTE skills include objectives that are related with understanding, interpretation and analysis of relationship among physics, society, technology and environment.

**Informatics and Communication Skills (ICS)**

Informatics (information technologies), communication and basic computer skills were given under ICS skills.

**Attitudes and Values (AV)**

The area of AV consists of self-control and self-development skills, organization and working skills, and scientific attitudes and values.

Objectives of the skills and content knowledge are not independent from each other. Objectives of skills were interwoven into content knowledge objectives. Details of objectives of the skills and content knowledge, and their relationship were presented with examples in the symposium.

As a result, the physics curriculum can be modeled as a fruit tree. In this model, students are represented by the tree, outcomes of skills are represented by roots and outcomes of content knowledge are represented by fruits. Water droplets are used to indicate that outcomes of skills and content knowledge support and feed each other. As a result, students will be engaged both with content knowledge and skills which are expected to be useful in students’ daily life. In other words, students will be able to integrate content knowledge learned in the course with skills obtained in the course in case of solving problems they encounter in their real life.
Learning-teaching and assessment approaches (LTAA)

In the Turkish Physics Curriculum,

- the LTAA cannot be discussed without clarity on content being taught, characteristics of students and teachers, allocated time for this process, and available materials and facilities of the classroom.

- the purpose of the LTAA is the most important factor to determine the selection of the LTAA. Therefore, the curriculum proclaims that there is no best method for the LTAA. The best method depends on these factors mentioned at the first. One method could be best for one case, another could be best for the other case. The best way is to change the methods according to the conditions and needs.

- the curriculum does not restrict itself to any of the learning approaches from constructivism to behaviorism. However, behaviorism has been widely used in the classrooms in Turkey like in other countries. Therefore, the curriculum now puts more emphasis on constructivism and less emphasis on behaviorism. Although all teaching methods could be used in physics classes, student-based methods have more emphasis than teacher-based methods in the curriculum.

- in the previous physics curriculum, the most commonly used purpose for the assessment in Turkey is summative. The new curriculum puts great emphasis on placement, formative and diagnostic purposes next to a summative purpose. Placement exams are suggested to be used.
in the beginning of the instruction. Formative and diagnostic exams are suggested to be widely used during and after the instruction. Authentic assessment (unobtrusive and performance based) techniques are suggested to be used as well as the most commonly used paper and pencil tests.

2.2 Influences of society’s desires on the curriculum

There are some influences on the curriculum reform efforts in terms of society’s desires. The most important of the influences is the University Entrance Exam (UEE) in Turkey. At the end of high school, following the 12th grade, students have to take and pass the University Entrance Exam (UEE) to continue their studies at a university. Thus, the UEE plays an important role in Turkish society and education system. The content of the UEE has impacts on classroom teaching practices. Although most parents and high school teachers think that new educational approaches are important for an effective instruction, they push their children (or students) to succeed in college and in UEE. For this reason, curriculum reforms may not be important for some parents and some teachers.

2.3 Influences of research results on the curriculum and its development

Firstly, the physics curriculum development committee examined reports and projects on curriculum reforms of other countries (Kanli and Serin, 2008). Some of these are as follows:

- England (the Salters Approach and SLIP)
- Germany (PiKO: Physics in Context)
- Finland (ROSE: The Relevance of Science Education)
- Israel (STEMS: Science, Technology Environment in Modern Society)
- USA (ChemCom: American Chemical Society)
- Netherlands (PLON: Dutch Physics Curriculum NiNa)

Secondly, curriculum developers used the results of three independent needs assessment studies to design and develop a physics curriculum. The participants of these studies include students from different levels (high school, undergraduate and graduate), teachers, research assistants, parents, academicians and people from other occupations.

- The first study was a survey conducted by the Education Research and Development Department. The sample of this study includes 342 teachers, 7541 students, and 1500 parents from two counties in each of the seven geographical regions of Turkey. The results of the study indicate not only major needs of students but also ideas and suggestions from teachers, parents, different parts of the Ministry of National Education and private schools. The second needs assessment study was the open-ended reports prepared by the committees constructed in 78 counties (out of 81) in Turkey and 10 governmental and civil organizations. These reports were analyzed by Turkish High School Physics Curriculum Development Committee by means of content analysis. The results provide a detailed account of the participants’ perceptions about which topics should be added and which ones should be discarded, which topics should be replaced with others and in which topics the content should be reduced etc.

- A questionnaire was the final needs assessment study, prepared by curriculum developers and posted on the Turkish Physics Curriculum website (2007) to obtain data from respondents from a wide range of educational level and occupation. The sample includes 204 respondents who are students (n=103), teachers (n=70), academicians (n=14) and others (n=17). According to the results, a majority of the participants indicates that the high school physics program should be developed in an interdisciplinary approach; cooperative learning should be encouraged in the program, the program should develop students’ higher order thinking skills and innovation.
3. Characteristics of the curriculum development process

The physics curriculum committee consists of eight academicians (three physicists and five physics educators) from six universities and three physics teachers from secondary education. In 2006, the curriculum committee started developing the physics curriculum. During about two years, the committee developed a list of benchmarks for a physics curriculum. Then the new physics curriculum for grade 9 was developed. It was begun to be implemented in school year 2008-2009. Other grades curricula were implemented in every consecutive year. The following figure shows the eight steps of the physics curriculum development process in Turkey.

The physics curricula from grade 9 to grade 12 have been revised based on teachers’, academicians’, and other stakeholders’ feedback. Today, the revised curricula are in use.

Sources on the web

www.fizikprogrami.com with documentation about physics curriculum


WCPE 2012, Istanbul, Turkey
References:


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Developing physics curricula in Korea: characteristics and development

Junehee Yoo, Seoul National University, Korea

Abstract

In the beginning of 2009, the Special Committee on National Curriculum of the PACEST (Presidential Advisory Council on Education, Science & Technology) gave directions for a National Curriculum reform, in order to meet the needs of creative human resources for the future society and of the overall implementation of a five-day work week. On the other hand, the Korean Physical Society and secondary physics teachers worried about radical reduction of student numbers who enrolled in Physics I as well as Physics II. To materialize the reform directions, the MEST (Ministry of Education, Science and Technology) installed committees on the general guidelines and all subject matters in parallel. As a result, the 2009 National Curriculum was announced just after a 1 year top-down project. The most noticeable changes are shifts to modern physics and cutting edge science and technology in everyday life. After another year of developing new textbooks, the 2009 National Curriculum was launched in 2011. During 2011, Physics I, which has been changed in a more drastic way, was implemented. Evaluations of Physics I vary according to stakeholders. Agile change of the National Curriculum to cope with radical changes of society would be a strong point. At the same time, the task to reach general consensus among stakeholders is crucial.

1. Background of new science curricula

1.1. Initiative for new science curricula

The 2009 National Curriculum has been developed and launched in a top-down way. In 2009, the Special Committee on National Curriculum of the PACEST (President Advisory Council on Education, Science & Technology) indicated the directions on how to reform the National Curriculum for the future (PACEST, 2009). The Special Committee pointed out facts to be addressed and directions as follows:

- The existing National Curriculum caused an excessively monolithic public and private education.
- → The National Curriculum must be constructed with the purpose of raising the quality of education, while leaving autonomy to schools to decide on their own school curriculum.
- Core competencies of global creative manpower for the 21st century need to be clarified in the curriculum and introduced in formal and informal education as soon as possible.
- → Reduction in the number of subjects and the burden of learning and assessment, and expansion of the department classroom system are needed.
- The National curriculum should be adjusted according to the overall implementation of a five-day work week.
- → Weekday classes need to be reinforced to reduce the amount of weekend classes. Also informal weekend programs by schools and local communities need to be associated with formal education.
- The above issues should be addressed as soon as possible even though the previous reform of the National Curriculum had started just 2 years ago.
- → The general guidelines of the National Curriculum need to be changed first, to adjust the management of school curricula and to enhance the outcomes of education.
Some data on Korea and education

- Total population (2012)\(^1\): 49.79 million
- GDP per capita (2012)\(^1\): USD 30,286
- Public spending (2011)\(^2\): USD 300 billion
- Public spending on education (2010)\(^3\): 5% of GNP, 20 % of GDP
- Private spending on education (2011)\(^4\): 3.1% of GNP
- Number of secondary schools (2012)\(^5\): 2,352 (from 10\(^{th}\) to 12\(^{th}\) grade)
- Number of secondary education students (2012)\(^5\): 1,935,704 (from 10\(^{th}\) to 12\(^{th}\) grade)
- Percentage of students in various streams (2012)\(^5\):
  - Academy high school : 68%
  - Vocational high school: 26%
  - Science high school : 0.2%
  - Language high school: 1.2%
  - Art high school: 0.9%
  - Athletic high school: 0.2%
  - Percentage of girl students : 47.1%
- The 5 day work week in school will be enforced overall from the year of 2012\(^6\)
- Total instructional time for students at upper secondary level is 1,020 hours per year. OECD average is 949(2010)\(^4\).
- Korean students’ learning time in school is around 40 hours and out of school is 13. OECD averages are 24 and 9.\(^7\)
- In the 2012 College Scholastic Ability Test, 13% of 621,336 applicants took Physics I and 3% Physics II.\(^8\)

1.2. Facts to be addressed

Following the directions of PACEST, the MEST installed committees on the general guidelines and all subjects in parallel for a year. As a result, the general guidelines and all subjects’ details of the 2009 National Curriculum have been developed and announced (MEST 2009a: MEST 2009b). The committees described the background of the curriculum reform from three perspectives: deficiency of current school education, customers’ needs and core competencies for the future society (MESTc, 2009). The perspectives are listed in the following.

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2 Retrieved from http://www.mosf.go.kr/lib/lib02.jsp
5 Retrieved from http://cesi.kedi.re.kr
• Deficiency of current school education
  - Korean students spend 15 hours more than the OECD average for their learning out of school in a week (OECD, 2004)
  - Inflexibility of curriculum management and excessive burden of study
  - Provider-centered curriculum management
  - Superficial management of extra-curricular activity
  - Extra-ordinary subdivision of elective subjects.

• Customers’ needs
  - Survey results reported that more than 70% of the sample teachers (n= 500) and parents (n= 500) agreed to shorten the period of a common national curriculum from 10 years to 9 years, to reduce the number of subjects for one semester by introducing the cluster system, and to enhance school autonomy, especially for instruction time (PACEST, 2009)
  - Survey results reported that more than 80% of the secondary students (N= 6,187) wanted less subject, more extra-curricular activity, more career education and more chance to choose subject (KEDI, 2008).

• Core competency for the future society
  - Knowledge-based society, new growth engine, green industry and global leader were extracted as keywords for future society. The core competency of future man-power should be creativity.

To address the above issues, the following four key features are emphasized in the 2009 National Curriculum (MEST, 2009a):

• Reduction of the number of subjects per semester
• Enhancement of basic core competency
• Provision of personalized education
• Introduction of creative experience activity.

In line with the general guidelines of the 2009 National Curriculum, the overall directions of the science curriculum were discussed. In that stage, the Korean Physical Society and Korean Association for Science Education got involved in the decision making process because many members of those affiliation were aware of the crisis in physics education. Through keen arguments, the final directions on the aims of this reform were as follows (Oh, 2012):

• Improve students’ interests in science through raising awareness of the value and usefulness of science and by emphasizing science as closely related with everyday life and other subjects
• Specify syllabus and achievement level descriptions
• Optimize subject contents by minimizing excessive repetition of contents due to a spiral curriculum structure and by integrating topics and clusters.

At the high school level, 9 science subjects are listed: Fusion Science, Physics I, II, Chemistry I, II, Biology I, II, Earth Science I, II (MEST, 2009b). Nine subjects share the aims of creativity with the general guidelines and inquiry skills for problem solving with the statement for all science subjects. Physics literacy and understanding of basic physics concepts are defined as specific aims of the physics curriculum. The summary of competencies which are defined in the physics curriculum is as follows:

• General competencies, identical for all subjects, e.g. creativity
• Science and technology competencies, in particular problem solving in everyday life and scientific inquiry, inquiry skills on the basis of understanding of nature of science, interests and curiosity
• Physics competencies, among which physics literacy and understandings of basic physics concepts.

The document of the physics curriculum includes, like the other subjects, descriptions of the characteristics, objectives, contents, instructional method, and assessments. In the following, the trials to narrow the gap between intended and performed curriculum are described.

**Intended and performed curriculum in Korean secondary education**

In a situation that an entry rate into tertiary education is 84% (OECD, 2012), leading university entrance rate is very important in senior secondary education. In many cases, the intended curriculum is distorted to achieve the needed high university entrance rates. It means that the scopes and levels of the performed curriculum are limited by the College Scholastic Ability Test which is a matter of primary concern to voters. Before the 2009 National Curriculum, levels of contents and how to teach them have been defined in the curriculum guide to regulate the performed curriculum. But as a side effect, these guides were regarded as a restriction for developing textbooks, because too many conditions were included. In the 2009 National Curriculum, a curriculum guide was left out in order to give more autonomy to textbook authors and publishers. As a result, two new Physics I textbooks were published in quite different ways and levels. Teachers are free to choose books they prefer and to use their own materials. But still, teachers are very keen to meet the level of test items of College Scholastic Ability Test to improve levels of their performed curriculum.

2. Characteristics of the new curriculum

The emphases of the Physics Curriculum shift from classical physics to cutting edge science and technology of modern civilization on the basis of modern physics, in order to enhance physics literacy both for future citizens and scientists (MEST, 2009b).

2.1 Domains of directions and objectives

The characteristics of Physics I are described as follows.

• Students are expected to understand natural phenomena and cutting edge science and technology and to cultivate physics literacy in their role of citizens in a democratic society.
• Basic physics concepts constructed around everyday life topics and basic concepts of modern physics are included comprehensively to raise students as citizens of future society with scientific literacy.
• Everyday topics and modern physics are learned by argumentation, experience and inquiry rather than by information conveyance.
• The contents of Physics I should be developed on the basis of understandings in students’ prior concepts, intellectual stage, experience, interests and cognitive learning processes as well as conceptual structures of physics. To encourage active learning for meaningful understandings, various learning strategies and activities should be included.
• The inquiry activities in physics I are described in line with understandings about the nature of science; complete inquiry processes – from the recognition of the inquiry problem to the conclusions – must be learned properly.
• Various activities such as experimental inquiry, reasoning, survey and discussion are performed and during these activities, creativity should be revealed and utilized.

2.2 Domains of concepts and contexts

Especially the contents of Physics I has been changed drastically, because the developers presumed that most of the students who take Physics I would have no more physics subjects and they must have chances to understand the foundation of Physics through learning modern physics without complex calculations. As a consequence, time-space and many topics of everyday technology were included to enhance the physics literacy for the future society.
for Physics I

- Time-space and universe
  - time measurement and standard, length measurement and standard, Newton’s law, momentum and impulse, conservation of mechanical energy
  - gravity, theory of relativity, black hole and gravitational lens, model of universe, the four interactions and basic particles
- Matter and electromagnetic field
  - electric field and force line, electrostatics, polarization, magnetic field and force line, induced currents and Faraday’s Law
  - energy level and radiation, energy band theory, semi-conductor, new materials
- Information and communication
  - sound waves, ultrasonic sound waves, harmonic sound and noise, microphone and electrical signal, photo electrical effect and light sensor, color perception and display
  - spectrum of EM waves, antenna and wireless communication, optical cable, A.C. and signal procedure, information storage equipment
- Energy
  - EMF, electrical energy, generator, nuclear power plant, nuclear fusion and solar energy, solar panel
  - torque, equilibrium and stability, fluid, thermal mechanics and heat engine, state change and weather, electrical energy

Physics II is somewhat similar to the traditional curriculum, but the last unit of quantum physics is regarded as unusual by high school physics teachers.

for Physics II

- Motion and Energy
  - position vector, laws of force and motion, parabolic and circular motion, accelerated coordinate and inertial force, simple harmonic motion
  - absolute temperature, gas molecule motion, equation state of hypothetical ideal gas, internal energy, thermodynamic processes, entropy
- Electricity and Magnetism
  - electric potential, electric potential, capacity, dielectric materials
  - magnetic field by electric current, magnetic flux and Faraday’s law, Lorenz force law, magnetic dipole
- Waves and Light
  - principles of Huygens, standing waves and resonance, refraction and reflection, diffraction and interference, Doppler effect and shock waves
  - mirror and lenses, optical instruments, x-ray and gamma ray, micro waves, laser, polarization
- Microscopic world and Quantum phenomena
  - wave-particle duality: Planck’s hypothesis, wave-particle duality. De Broglie wave length and wave nature of particles, electron microscope
  - Quantum Physics: uncertainty principle, Schrödinger equation, wave function, atomic model, energy level, quantum tunneling effect

Instructional methods and assessments followed the domains of contents.
2.3 Pro and cons on Physics I

Inclusion of modern physics in Physics I was regarded as a drastic decision, because there was no solid evidence supporting the presumptions of Physics I and no sufficient research results of how to teach modern physics to upper secondary students. After one year of implementation, one of the prominent positive opinions of physics teachers is that the modern topics of Physics I could invoke students’ interest. On the other hand, physics teachers appeal that too many concepts are listed in the 2009 curriculum without a detailed description of scopes and levels. Many teachers argue that they just scanned the terms listed in the curriculum in the given time and they have difficulties in making test items as well as teaching materials even though they got professional development trainings. Evidence based curriculum evaluation results are expected at this moment.

3. Characteristics of the curriculum development process

3.1 Issues in developing physics curricula

The frequency of curriculum change

In Korea, the usual period of curriculum change was 5 years. But the 2009 National Curriculum was changed just after the 2007 curriculum had been launched. Another 2 years later, one more key word, STEAM (Science Technology, Engineering, Art and Mathematics), was added into the 2009 National Curriculum and some contents of science textbooks had to be realigned to the new key word. These swift adaptations may be good for timely addressing needs of society, but they may create deficiencies because of lacking developing time. Still, MEST is looking at what would be the proper period of curriculum change.

Top-down process

The 2009 National Curriculum has been developed in a two year project including textbook development. This kind of strong top-down drive by MEST was the only possibility to have the reform launched in time. On the other hand, the introduced agendas and presumptions couldn’t be investigated sufficiently, and selecting and organizing content didn’t have enough time to get consensus among different stakeholders. In many cases, the key words of the new curriculum became research topics after introduction of new curriculum, as Table 1 shows. The numbers of research papers which are related to each curriculum keyword increased after implementation of new curriculum. These data can be interpreted in two ways. Firstly, science education researchers may be a little bit behind in awareness of social trends which evolve continuously. Or policy makers may propose key words without enough evidence and consensus, and then researchers try to define and justify the key words. A new key word may turn into a very fruitful vision, or be unmasked as an air castle.

Table 1: Number of Research Papers related to Keywords of National Curriculum by June, 2012

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↑: In the corresponding year, the keyword was introduced in the National Curriculum.

Different expectations on educational outcome and core competency

In Korea, education is one of the primary concerns of every family. The fact that expenditure for education from the private sector is the highest among the OECD countries could reflect it (OECD, 2012). Parents are very interested in their kids’ university entrance which is supposed to guarantee the kids’ future job opportunities and income. Policy makers should be interested in human resource for the future society and labor market, while some politicians are just interested to meet the parents’ needs to get more votes.
The industry as well as the academic society needs high competency manpower, whatever the future generations’ preferences of specific jobs may be. Different researchers may have different solutions to the same issue. Schools and teachers in the field may be among the other stakeholders, even though they are the final executors of new curriculum.

3.2 Tasks for the Future

How to share data and visions of macro and micro levels among stakeholders?

After one year implementation of the new Physics I curriculum, physics teachers who felt difficulties in teaching Physics I and researchers who agree with those teachers started gathering and analyzing data on students’ achievements in the field, spontaneously. Also they are sharing the teaching materials and instruction tips on modern physics for high school students. These kinds of grass root and microscopic data gathering can direct how to adjust the new curriculum and induce new visions on the ground. The task is how to share the microscopic data and visions with stakeholders with macroscopic indicators.

Literature


OECD (2012). Education at a Glance 2012: OECD Indicators. OECD.


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High School Physics in the United States

Jacqueline D. Spears, Kansas State University jdspears@ksu.edu

Abstract

This paper presents an overview of high school physics in the United States, focusing primarily on the numbers of students who complete at least one physics course in high school, the types of courses in which these students enroll, and the extent to which these courses serve a diverse student population. Closing sections describe physics teachers’ access to educational research and the themes currently represented in the research literature as well as the challenges high school physics teachers face in contemporary classrooms.

Introduction

Over the past twenty years the number of high school students completing one or more physics courses in the United States has increased substantially. This growth in enrollment has occurred in the midst of efforts to define nationwide science standards as well as despite a number of demographic challenges facing the American educational system. This paper presents background on the American educational system important to understanding the context within which physics courses are offered, shares data descriptive of physics course-taking patterns among American high school students, identifies the ways in which physics teachers gain access to educational research, and discusses current challenges.

Background

A number of features of the American educational system differ from systems in other countries and help establish the larger context within which high school physics courses are offered in the United States. These include the role of schools within the larger culture, the extent to which schooling is seen as a state rather than national responsibility, the variation in how schools are funded, and recent efforts to standardize educational practice across this diversity.

As is probably true in most countries, the role that schools play in the larger culture has continued to evolve in response to national social and economic needs. In the United States, public education arose initially from the need to integrate immigrant populations into a shared national culture. Although that remains a goal of contemporary education, other purposes have been added. Ideally, schools are seen as the mechanism by which individuals gain social mobility. In theory, a publically supported education system should enable those born into poverty to improve their social and economic position through education that prepares them for higher paying employment. As the available employment has shifted from skilled labor and manufacturing jobs to what are now perceived to be more demanding skills linked to the integration of technology into industry as well as the growth of the information age, the need for education has expanded to include some sort of postsecondary education. States increasingly think in terms of establishing K-16 systems of education designed to support the transition from K-12 education to some sort of technical training or university education linked to employment. Moreover, education is seen as an economic driver for both local community development as well as national competitiveness in a global economy. Finally, the American population continues to become increasingly diverse. Public schools are seen as the venue through which young people can be taught to respect differences in cultures as well as learn the collaborative skills necessary to working effectively within a diverse society.

A second feature that is probably unique to the American educational system is its diversity. The Tenth Amendment to the U.S. Constitution defines all powers not delegated to the federal government by the Constitution to be the responsibility of the individual states. Consequently, education is the responsibility of the 50 states. That translates into 50 different systems of education. Moreover, most states defer to school districts that are funded and controlled by locally elected school boards. In short, there are more than 14,000 school districts that spend approximately $500 billion dollars on education annually. As shown in Table I, the diversity in funding sources for public schools is enormous. Over time, funding for public schools has moved from being primarily a local responsibility to what is increasingly defined as...
responsibility shared between local and state taxes. The federal government has remained a minor player in supporting public education. Still, as shown in Table 1, there is considerable variability across the 50 states in terms of the percent of educational costs borne by localities, states, and the federal government. This decentralized system of public schools has led to substantial differences in quality of education as well as challenges in accommodating students who move from one state to another.

Table 1: Sources of Funds for K-12 Schools*

<table>
<thead>
<tr>
<th>Source of Funding</th>
<th>Average Across States</th>
<th>Range Across States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local taxes</td>
<td>44%</td>
<td>3% - 60%</td>
</tr>
<tr>
<td>State taxes</td>
<td>46%</td>
<td>31% - 86%</td>
</tr>
<tr>
<td>Federal taxes</td>
<td>10%</td>
<td>4% - 16%</td>
</tr>
</tbody>
</table>

* National Center for Education Statistics, 2011

One important facet of American education to understand is what continues to be decisions made within competing social values. In general, decisions related to education depend on preferences for efficiency, quality, equity, and/or choice (Mitchell, Marshall, & Wirt, 1986). Decisions related to efficiency often focus on the number of students/teacher or the number of administrators/district in an effort to limit the cost of education. Issues related to quality focus on the extent to which educational programs serve the most capable of the nation’s young people. Issues related to equity focus on the need for educational programs that best serve the diversity of learners in the American educational system. Finally, decisions related to choice focus on relying on local school boards to link school funding to choices that the local population will support through local taxes. Changes in educational policy often reflect differences in which of the four values should be emphasized. Although education is generally perceived to be a local responsibility, both state and the federal government have become more involved because of concerns with educational equity.

Finally, over the past twenty years there have been a number of efforts to introduce some common ground across the diversity of school districts that exist. Rather than focusing on developing a national curriculum, which many states would challenge as inappropriate, these efforts have sought to establish common student learning outcomes. In 1996 the National Research Council released the National Science Education Standards. In addition to standards specific to each of the content areas (life science, physical science, and earth and space science), this document outlined standards specific to unifying concepts and processors, science as inquiry, science and technology, science in personal and social perspectives, and history and nature of science. In 2012 the National Research Council released a document establishing a framework for a new set of science education standards referred to as the Next Generation Science Standards (NGSS). These new standards integrate a series of eight science and engineering practices with six cross-cutting concepts (e.g., cause and effect) with disciplinary core ideas in life science, physical science, and earth and space science. Final versions of these standards are expected to be available in March 2013 at which point states will decide whether to adopt the new standards for use in their schools. These new science education standards integrate engineering more deliberately in science classrooms as well as engage students more deeply in the process by which scientists establish scientific knowledge and engineers design solutions to problems.

High School Physics Courses and Enrollments

Although there is considerable variability in the high school curriculum across the 50 states, for the most part physics is one of several science courses available to high school students. Most school districts require students to complete courses in the life sciences, physical sciences, and earth and space sciences as part of their middle-school experience. At the high school level, students are then allowed to choose from among high school biology, physics, chemistry, and specialty courses such as environmental science. Prior to the development of shared science education standards, science teachers typically designed the courses to be made available in high school. Although high school physics and high school chemistry courses were often shaped by university expectations, high school biology courses ranged from survey
courses to specialty courses in anatomy and physiology, oceanography, ecology, etc. The introduction and use of national science education standards, however, has reduced some of the variability in biology courses over the past 10-15 years.

Nearly all high school students complete a biology course. Fewer students complete a chemistry course and fewer still complete a physics course. As shown in Table 2, however, the percentage of high school students completing one or more physics courses has increased substantially in the last twenty years.

**Table 2: Percentage of High School Students Completing One or More Physics Courses***

<table>
<thead>
<tr>
<th>Decade</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940s</td>
<td>25%</td>
</tr>
<tr>
<td>1950s</td>
<td>23%</td>
</tr>
<tr>
<td>1960s</td>
<td>20%</td>
</tr>
<tr>
<td>1970s</td>
<td>17%</td>
</tr>
<tr>
<td>1980s</td>
<td>19%</td>
</tr>
<tr>
<td>1990s</td>
<td>28%</td>
</tr>
<tr>
<td>2000s</td>
<td>33%</td>
</tr>
</tbody>
</table>


Based on a survey conducted by the American Institute of Physics (AIP) in 2009, this increased enrollment is spread across a number of different types of physics courses made available at the high school level. Table 3 shows the percent of students completing each of six different course options reported by high school physics teachers. Differences across physics courses are typically defined by the extent to which mathematics is integrated into the content. As shown in Table 3, total student enrollment in high school physics courses is largest in the traditional algebra-based physics course designed to prepare students for algebra-based or calculus-based physics at the university level. Enrollments in courses that limit the amount of mathematics incorporated into the course (Physics First, Conceptual Physics, and Regular Physics using a conceptually-based textbook) and enrollments in more advanced course, however, are roughly equal. Physics teachers have considerable freedom in courses designed as Honors Physics courses but are constrained to a prescribed curriculum in advanced placement courses.

**Table 3: 2009 Percent of Student Enrollment Across Physics Course Options***

<table>
<thead>
<tr>
<th>Physics Course Options</th>
<th>Percent Student Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics First (Pre-Algebra/Algebra I)</td>
<td>6%</td>
</tr>
<tr>
<td>Conceptual Physics (little to no mathematics)</td>
<td>12%</td>
</tr>
<tr>
<td>Regular Physics (using conceptual textbook)</td>
<td>13%</td>
</tr>
<tr>
<td>Regular Physics (algebra-based)</td>
<td>37%</td>
</tr>
<tr>
<td>Honors Physics (more depth and breadth)</td>
<td>19%</td>
</tr>
<tr>
<td>Advanced Placement Physics (with/without calculus)</td>
<td>13%</td>
</tr>
</tbody>
</table>


Interestingly enough, as shown in Table 4, the growth in the percentage of high school students completing one or more physics courses from 1987 to 2009 has occurred among conceptual and honors/advanced placement courses while enrollments in the traditional algebra-based high school physics course have remained relatively stable.
Table 4: Growth in Enrollments from 1987 to 2009*

<table>
<thead>
<tr>
<th>Physics Course Options</th>
<th>Change in Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics First (Pre-Algebra/Algebra I)</td>
<td>25,000 to 400,000</td>
</tr>
<tr>
<td>Conceptual Physics (little to no mathematics)</td>
<td></td>
</tr>
<tr>
<td>Regular Physics (using conceptual textbook)</td>
<td>Stable at 500,000</td>
</tr>
<tr>
<td>Regular Physics (algebra-based)</td>
<td></td>
</tr>
<tr>
<td>Honors Physics (more depth and breadth)</td>
<td>94,000 to 437,000</td>
</tr>
<tr>
<td>Advanced Placement Physics (with/without calculus)</td>
<td></td>
</tr>
</tbody>
</table>


Clearly, the introduction of course options that emphasize conceptual rather than mathematical approaches to physics has had the most dramatic impact on high school student enrollment in physics courses.

**Equity Concerns**

A long-standing concern in the American educational system has been the lower rates at which women and members of populations under-represented in the sciences typically complete physics courses. Completion of an algebra-based high school physics course is often considered critical to student success in engineering, mathematics, and science programs at the university level. Tables 5 and 6 compare male and female student completion of one or more high school physics courses and the distribution of those enrollments across the high school physics course options.

Table 5: Percent of Males and Females Completing One or More High School Physics Courses*

<table>
<thead>
<tr>
<th>Year</th>
<th>Percent Males</th>
<th>Percent Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>61%</td>
<td>39%</td>
</tr>
<tr>
<td>1998</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>2005</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>2009</td>
<td>53%</td>
<td>47%</td>
</tr>
</tbody>
</table>


Clearly the increase in the number of high school students completing one or more physics courses in the 1990s and 2000s was accompanied by a substantial increase in the percentage of females completing one or more high school physics courses from 1987 to 2009. Since 1998, however, that time, the percentage of women completing one or more physics courses in high school has remained relatively constant. Table 6 shows how the percentage of males and females compared across the physics course options available in 2009. The various conceptual course options presented in Table 3 have been collapsed to a single category in Table 6. In addition, percentages of males and females completing algebra-based Advanced Placement Physics (AP-B) and calculus-based Advanced Placement Physics (AP-C) have been broken out.

Table 6: Percentage of Males and Females in Physics Course Options – 2009*

<table>
<thead>
<tr>
<th>Physics Course Option</th>
<th>Percent Males</th>
<th>Percent Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual Physics &amp; Physics First</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Regular Physics</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>Honors Physics</td>
<td>51%</td>
<td>49%</td>
</tr>
<tr>
<td>Advanced Placement – Algebra Based</td>
<td>59%</td>
<td>41%</td>
</tr>
<tr>
<td>Advanced Placement – Calculus Based</td>
<td>68%</td>
<td>32%</td>
</tr>
</tbody>
</table>

As shown in Table 6, the percentages of males and females completing the various physics course options differ substantially for the two Advanced Placement options. Although the percentage of women completing a conceptual physics course exceeds that of men, the percentages of men and women completing an honors physics course are relatively close. Female participation in Advanced Placement courses drops considerably, however. Given that these courses provide better preparation for required university physics courses and can enable students to earn college credit for those courses, the lower participation of women is thought to contribute to the lower numbers of women enrolled in engineering, science, and mathematics programs at the university level.

Finally, there is considerable variability in the rates at which members of various ethnic groups complete high school physics courses. Table 7 shows the percentage of high school students completing at least one physics course in 2009.

Table 7: Percentage of High School Students Completing One or More Physics Courses – 2009*

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anglo-American</td>
<td>40%</td>
</tr>
<tr>
<td>African-American</td>
<td>20%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>20%</td>
</tr>
<tr>
<td>Asian</td>
<td>47%</td>
</tr>
</tbody>
</table>


As is evident in Table 7, both the African American and Hispanic populations remain seriously under-represented among high school students completing one or more physics courses. While some progress has been made in increasing the participation of women in high school physics, the participation of African-American and Hispanic youth remains vastly different than the rates among Anglo-American and Asian youth.

Educational/Pedagogical Research

Teachers gain access to ongoing research related to physics education through a number of venues. As part of their undergraduate preparation in education, all prospective physics teachers complete a science methods course that incorporates current physics education research from relevant journals. There are two journals published through the American Institute of Physics that provide information specific to physics education. *The Physics Teacher* shares information specific to teaching techniques and classroom innovations relevant to high school and the first two years of university-level physics courses. *The American Journal of Physics* includes information specific to upper-level university physics courses as well educational research specific to both high school and university level physics. *The Journal of Research on Science Teaching* and *Science Education* publish educational research in all science disciplines across all grade levels. In general, however, high school physics teachers express far more interest in journals that present ideas and information specific to classroom practice.

Once in the classroom, physics teachers rely on research syntheses that are typically integrated into the national science education standards, summer workshops offered through universities, and course work connected with graduate work in education. Many school districts provide significant salary increases when teachers complete a master’s degree in either education or a specific discipline. Other salary increases are connected to teachers’ participation in relevant professional development opportunities. So practicing teachers gain further exposure of physics education research through course work completed as part of the master’s degree and summer workshops offered through universities. Summer workshops typically focus on challenges physics teachers face in implementing the national science education standards and/or emerging issues such as climate change, food safety, or nanotechnology. Educational research is embedded into the workshop format and teachers are then supported in developing lesson plans that are consistent with that research.
Much of the physics education research relevant to high school physics teachers reflect long-standing issues as well as challenges emerging as part of the changes in national science education standards. Research themes that remain consistently a part of physics education include: (1) misconceptions and/or preconceptions about physics concepts that students bring to the classroom, (2) learning progressions that characterize the age level and order in which increasing sophisticated presentation of concepts should be integrated into the classroom, (3) classroom interventions that increase the participation of women and members of populations under-represented in physics, and (4) methods of student engagement, such as inquiry, guided inquiry, small group discussion, Socratic circles, etc. The rapid increase of high school students for whom English is not their native language has also stimulated a great deal of research on how to sustain conceptual growth in subject matter areas taught in English while those students are simultaneously acquiring English skills. Finally, there are a number of research themes that more directly address the emphasis that national science education standards now place on science and engineering practices. In the past decade there has been an increase in research articles dealing with interventions designed to help students gain skills in argumentation, specifically argumentation based upon evidence. The Next Generation Science Standards include an emphasis on teaching students how to build and use models. If broadly adopted by the states, these new standards will undoubtedly stimulate considerable research on interventions designed to teach modeling.

**Current Challenges**

Physics teachers in the United States face a number of challenges, some dealing with long-standing concerns such as increased participation of women and members of populations under-represented in physics and others arising from more recent demographic and economic changes. The concern underlying both challenges is the perceived need for the United States to produce more scientists, for local economic development as well as for international competitiveness. Understanding how high school physics teachers could be successful in encouraging women as well as African American and Hispanic men and women to become engaged in physics will remain a persistent need. Coupled with the realization that larger numbers of young people immigrate with their families to the United States at middle and high school age rather than as infants or young children has increased the need for interventions that more effectively engage students in careers in physics. Many of these older students have the intellectual skills to succeed but fall behind in science courses because of their unfamiliarity with English. Strategies that support continued conceptual growth in physics courses as these students acquire English language skills are critical.

A second challenge is the extent to which national science education standards developed for K-12 education widens the gap between what physics teachers are expected to teach and what physics content they are exposed to at the university. Most university physics courses focus on delivering physics content, which is certainly very important. Starting with the National Science Education Standards adopted in 1996 and continuing with the Next Generation Science Standards being considered for adoption, physics teachers are being expected to teach science as inquiry, the history and nature of science, and now a series of science and engineering practices. When science as inquiry and the history and nature of science were first introduced as part of the standards in 1996, colleges of education were able to respond by incorporating that content in their science methods courses. Given that a science methods course includes undergraduates planning to teach biology, chemistry, geology, or physics, those classroom discussions were especially rich. The science and engineering practices included in the Next Generation Science Standards, however, include practices such as ‘developing and using models’ and ‘constructing explanations/designing solutions.’ These are practices that are currently not included in the physics content classes.

Finally, there is a growing gap between the physics taught in the high school classroom and the new knowledge being built. Although physics textbooks and electronic resources have become increasingly more accessible and helpful to physic teachers, most of the content included in these materials has not changed in 50-60 years. Emerging fields such as nanotechnology are rarely addressed, leaving high school students assuming that there is nothing left to discover in physics. Physics researchers and physics teachers need to find ways to incorporate emerging knowledge into high school physics courses.
References


