sciED

Scientia in educatione 8(Special Issue), 2017

ISSN 1804-7106

CONTENTS

Editorial

Keynote lectures

Selected papers

EDITORIAL

This special issue of *Scientia in Educatione* is devoted to publishing keynotes and further selected papers from *the International Conference on Physics Education*, ICPE-EPEC 2013, that took place in Prague, Czech Republic, 5.–9. 8. 2013. Though some time has passed since the conference, we think that publishing these papers does not serve just the purpose to archive (the best of) what was presented there. In fact, freely available Proceedings published a year after the conference already offered all contributions and presented a broad range of ideas that had been shared by 311 participants from 55 countries. However, we feel important to present selected papers in a form of a special journal issue as it can help them to be "more visible" to a community of physics educators and researchers in the field of science education research; these papers really deserve it.

There is also another reason why it still makes sense to publish selected and keynote papers here. The general focus of the conference, *Active learning — in a changing world of new technologies*, stays to be very important and challenging and the papers in the special issue are an undoubtedly useful and inspiring source of information and inspiration concerning this topic.

All six keynotes concerning physics education and physics education research presented at the conference are published in this issue. (One other keynote published in the Proceedings was more oriented towards physics so, in agreement with its author, it is not presented here.) These keynote papers are arranged here in the same order in which they were presented at the conference. From other 158 papers, 21 were selected to be published in this issue, taking into account the evaluation of reviewers and chairs of sessions. These papers are arranged in an alphabetic order according to the authors' names. All papers presented here are in the same form in which they were written by the authors after the conference for its Proceedings with just a small number of corrections or very minor updates. (One formal point is that all references were transformed into APA style to conform to the rules of this journal.)

It should be noted that selected contributions are not limited to oral presentations only; workshops and posters were included, too. In fact, from the total number of 171 oral talks at the conference 17 papers are presented below; from fifteen workshops two were selected as well as two from 120 posters. Also, all three loosely defined categories of contributions, "research", "classroom ideas" and "mixed", are among selected papers. ("Classroom ideas" are represented by just two papers and, of course, even their ideas are research-based.) Papers also naturally cover a broad range of physics areas. Moreover, authors from 17 countries present their papers in this issue, ranging from Canada, Mexico and Brazil to Japan, Philippines and Australia. Therefore, the diversity of conference contributions seems to be reflected in this special issue quite well.

We hope that this collection of keynotes and other papers will serve as a useful and inspiring source of information and ideas to physics educators and researchers in this field — perhaps in even more than 55 countries the participants of the conference came from.

Prague, March 20th, 2017

Leoš Dvořák,
Editor of this special issue

Keynote lectures

Scientia in educatione 8(Special Issue), 2017
p. 6–21
ISSN 1804-7106

Using Physics to Help Students Develop Scientific Habits of Mind

Eugenia Etkina

Abstract

Interactive engagement curricula are successful in helping students develop conceptual understanding of physics principles and solve problems. However, another benefit of actively engaging students in the construction of their physics knowledge is providing them with an opportunity to engage in habitual "thinking like physicists". Some examples of such thinking are: drawing a sketch before solving any physics problem, subjecting normative statements to experimental testing, evaluating assumptions, or treating each experimental results as an interval. We can help students develop these "habits of mind" if we purposefully and systematically engage them in the processes that mirror the processes in which physicists engage when they construct and apply knowledge. For such engagement to occur, we need to deeply re-conceptualize the role of experiments in physics instruction and their interaction with the theory. However, most importantly, we need to rethink the role of the instructor in the classroom.

ACKNOWLEDGEMENT

Work reported in this talk is the result of collaboration of many people. Before I begin, I would like to acknowledge important contributions of S. Brahmia, D. Brookes, C. D'Amato, M. Gentile, C. Hmelo-Silver, R. Jordan, A. Karelina, S. Murthy, G. Planinsic, D. Rosengrant, M. Ruibal-Villasenor, A. Van Heuvelen, A. Warren, and X. Zou. Without them the material presented here would not exist.

1 INTRODUCTION

What knowledge and what abilities are needed to succeed in this 21st century workplace? This question has been addressed by individual research studies examining the need for various process abilities and for declarative knowledge of people in that workplace (Chin, et.al., 2004; Coles, 1997; Gott, et.al., 1999; Lottero-Perdue, et.al., 2002). Duggan and Gott (2002: p. 756–782) studied the science used by employees in five science-based industries: a chemical plant specializing in cosmetics and pharmaceuticals, a biotechnology firm specializing in medical diagnostic kits, an environmental analysis lab, an engineering company manufacturing pumps for the petrochemical industry, and an arable farm. They found that most of the scientific conceptual understanding used by employees was learned on the job, and not in high school or university courses. They concluded: "A secure knowledge of procedural understanding appeared to be critical."

Aikenhead (2005: p. 242–275) summarized his own and other studies as follows: "In science-rich workplaces, procedural knowledge had a greater credence than declarative knowledge (Chin, et.al. 2004) and employees consistently used concepts of evidence in their work to such an extent that Duggan and Gott (2002) concluded: procedural knowledge generally, and concepts of evidence specifically, lie at the heart of... science-based occupations."

In addition to individual research studies like these, there have been a plethora of national studies and reports concerning desired outcomes of science education (Czujko, 1997[1]; Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop, 2003; Educating the Engineer of 2020: Adapting Engineering Education to the New Century, 2005). Recently published Next Generation Science Standards (2013) used the term "science practices" and made those as important for student learning as the content of science itself. In this paper I will use the term "scientific abilities" coined and used by the Physics Education Research group at Rutgers University to describe our work and findings in this area.

2 SCIENTIFIC ABILITIES

We started the scientific abilities project started in 2003 by identifying the most important procedures, processes, and methods that scientists use when constructing knowledge and when solving experimental problems. The list of scientific abilities that our physics education research group developed includes (A) the ability to represent physical processes in multiple ways; (B) the ability to devise and test a qualitative explanation or quantitative relationship; (C) the ability to modify a

---

[1] Updated standards are available at http://www.abet.org/accreditation-criteria-policies-documents/.

qualitative explanation or quantitative relationship; (D) the ability to design an experimental investigation to develop a new concept, test a concept or apply a set of concepts to solve a practical problem; (E) the ability to collect and analyze data; (F) the ability to evaluate experimental predictions and outcomes, conceptual claims, problem solutions, and models, and (G) the ability to communicate.

To help students develop these abilities, one needs to engage students in appropriate activities, and to find ways to assess students' performance on these tasks and to provide timely feedback. Activities that incorporate feedback to the students are called formative assessment activities. Specifically, the students need to understand the target concept or ability that they are expected to acquire and the criteria for good work relative to that concept or ability. They need to be able to assess their own efforts in light of the criteria. Finally, they need to share responsibility for taking action in light of the feedback. The feedback should be descriptive and criterion-based as opposed to grades without clear criteria.

In real life, how can one make formative assessment and self-assessment possible?

One way to implement formative assessment and self-assessment is to use self-assessment rubrics. An assessment rubric allows learners to see learning and performance goals, self-assess their work, and modify it to achieve the goals. A rubric contains descriptions of different levels of performance, including the target level. Students can use the rubric to help self-assess and improve their own work. Instructors can use the rubric to evaluate students' work and to provide feedback.

After making the list of scientific abilities that we created rubrics to help students self-assess themselves and improve their work. The process through which we developed and validated the rubric is described in detail in (Etkina & Van Heuvelen, et.al., 2006). The most important part of the work was that we found that it is impossible to assess each ability from the list above as one unit. For the purposes of development and assessment we had to break each ability into smaller sub-abilities (total of 39 items). For example, for the ability to collect and analyze data we identified the following sub-abilities: (i) the ability to identify sources of experimental uncertainty, (ii) the ability to evaluate how experimental uncertainties might affect the data, (iii) the ability to minimize experimental uncertainty, (iv) the ability to record and represent data in a meaningful way, and (v) the ability to analyze data appropriately. Figures 1 and 2 below shows examples of several rubrics (all of them are available at http://paer.rtugers.edu/scientificabilities).

Figure 1 shows rubrics for several sub-abilities of the ability to represent information in multiple ways and Figure 2 shows rubrics several sub-abilities of the ability to design experimental investigation. Each item in the rubrics corresponds to one of the sub-abilities. The scale of 0–3 in the scoring rubrics (0, missing; 1, inadequate; 2, needs some improvement; and 3, adequate) was found to be the easiest when writing the rubrics and also later when we needed to achieve inter-rate reliability scoring student work (see examples in the Figures 1 and 2).

3 Investigative Science Learning Environment

Obviously, the rubrics alone are not enough to help the students learn to think like scientists. They need to be engaged in the activities that mirror scientific practice. Many inquiry-based curricula have individual activities that engage students in some of the practices, but there are a few which do it systematically and purposefully. One of those is Investigative Science Learning Environment (ISLE).

Ability to represent information in multiple ways

Scientific Ability	**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
Representations students can make				
Picture	No representation is constructed.	Picture is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing.	Picture has no incorrect information but has either no or very few labels of given quantities. Majority of key items are drawn in the picture.	Picture contains all key items with the majority of labels present. Physical quantities have appropriate subscripts
Force Diagram	No force diagram is constructed.	Force diagram is constructed but contains major errors: missing or extra forces (not matching with the interacting objects), incorrect directions of arrows or incorrect relative length of force arrows.	Force diagram contains no errors in force arrows but lacks a key feature such as labels of forces with two subscripts or forces are not drawn from single point.	The diagram contains all appropriate force and each force is labeled so that one can clearly understand what each force represents. Relative lengths of force arrows are correct.
Motion Diagram	No motion diagram is constructed.	The diagram does not represent the physical process accurately, either spacing of the dots or the directions and length of v arrows or delta v arrows do not match the motion.	The diagram matches the process but is missing one key feature: dots that represent position or velocity arrows, or delta v arrows.	The diagram contains no errors in dots, v arrows or delta v arrows and it clearly matches the motion of the object.
Mathematical	No representation is constructed.	Mathematical representation lacks the algebraic part (the student plugged the numbers right away) has the wrong concepts being applied, signs are incorrect, or progression is unclear. The first part should be applied when it is appropriate.	There are no errors in the reasoning, however they may not have fully completed steps to solve problem or one needs effort to comprehend the progression.	Mathematical representation contains no errors and it is easy to see progression from the first step to the last step. The final answer is reasonable in terms of magnitude, has correct units and is makes sense for the limiting cases.

Figure 1: Sub-abilities of the ability to represent information in multiple ways

Scientific Ability	**Missing**	**Inadequate**	**Needs some improvement**	**Adequate**
Is able to identify the phenomenon to be investigated	No mention is made of the phenomenon to be investigated.	An attempt is made to identify a phenomenon to be investigated but is described in a confusing manner, or is not the phenomena of interest	The phenomenon to be investi-gated is described but there are minor omissions or vague details.	The phenomenon to be investigated is clearly stated.
Is able to design a reliable experiment that investigates the phenomenon	The experiment does not investigate the phenomenon.	The experiment involves the phenomenon but due to the nature of the design it is likely the data will not contain any interesting patterns.	The experiment investigates the phenomenon and it is likely the data will contain interesting patterns, but due to the nature of the design some features of the patterns will not be observable.	The experiment investigates the phenomenon and there is a high likelihood the data will contain interesting patterns. All features of the patterns have a high likelihood of being observable.
Is able to decide what is to be measured and identify independent and dependent variables	The chosen measurements will not produce data that can be used to achieve the goals of the experiment.	The chosen measurements will produce data that can be used at best to partially achieve the goals of the experiment.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. However, independent and dependent variables are not clearly distinguished.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. Independent and dependent variables are clearly distinguished.
Is able to use available equipment to make measurements	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.
Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental set-up.	No description is mentioned.	A description is mentioned but it is incomplete. No picture is present. Or, most of the observations are mentioned in the context of prior knowledge.	A description exists, but it is mixed up with explanations or other elements of the experiment. A labeled picture is present. Or some observations are mentioned in the context of prior knowledge.	Clearly describes what happens in the experiments both verbally and by means of a labeled picture.

Figure 2: Rubrics for several sub-abilities of the ability to design an experiment to investigate a phenomenon

ISLE (Etkina & Van Heuvelen, 2007) (developed in 1985–2000 first for high school physics and then for college physics) engages students in the processes that mirror scientific practice to help them learn physics. Specifically, students start learning a new concept by observing a few very simple experiments (called observational-experiments). They then use available representations (motion diagrams, graphs, force diagrams, energy bar charts, etc.) to identify patterns, develop multiple explanations for those patterns and finally, test the explanations (with the purpose of ruling them out). The testing involves first designing a new experiment, the outcome of which they can predict using their explanation, second conducting the experiment, and third comparing the predictions to the outcomes of the testing experiment. This purposeful testing of proposed explanations using hypothetico-deductive reasoning is one of the most important features of ISLE, which in turn directly reflects common reasoning in science and, in particular, in experimental physics. Often the unexpected outcome of a testing experiment serves as an observational experiment for a new cycle.

The ISLE framework was developed to help students construct new concepts (Etkina & Van Heuvelen, 2007), however it can be successfully utilized when students apply the concepts that they have already constructed to analyze complex phenomena (Etkina, Planinšič & Vollmer, 2013). Recently and introductory physics textbook using ISLE approach with the supporting workbook for the students and an instructor guide for the teachers has been published (Etkina, Gentile & Van Heuvelen, 2013a; Etkina, Gentile & Van Heuvelen, 2013b; Etkina, Brookes & Van Heuvelen, 2013).

4 DEVELOPING SCIENTIFIC ABILITIES IN AN ISLE-BASED COURSE

Over the last 10 years we conducted multiple studies investigating how introductory students develop scientific abilities in an ISLE-based course in which most of the activities (including instructional labs where the students design their own experiments using scientific abilities rubrics) engage students in the processes that mirror scientific practice. In this section I will present brief summaries of those studies with relevant references so the reader can find the original papers and explore the details. Numerous examples of the activities that students do, including all laboratory investigations can be found at http://paer.rutgers.edu/scietificabilities.

4.1 STUDY OF MULTIPLE REPRESENTATIONS

This study is reported in the paper by Rosengrant, Van Heuvelen and Etkina (2009). The study investigated how students who learned physics through ISLE with an explicit focus on representing phenomena in multiple ways use those representations when they are solving problems on their own (an explicit focus involves several things: teaching students to construct a mathematical representation of the problem using one of the concrete representations; asking them to represent the problem situation without solving for anything and engaging them in Jeopardy-type problem where the solution is provided and the students need to recreate the problem situation and represent it in multiple ways; all of those multiple representation activities are provided in reference 15 and two examples are in Appendix 1 in this paper). Specifically, the study investigated the use of free-body (force) diagrams by students in a large enrollment (700 students) algebra-based general physics course. It was a two-year quantitative and qualitative study of students' use of free-body diagrams while solving physics problems. We found that when students are in a course that consistently emphasizes the use of free-body diagrams in the context of ISLE, the majority of them (60–70 % as opposed to 15 % in a traditionally taught course) do use diagrams on their own to help solve exam problems even when they receive no credit for drawing the diagrams (to make this conclusion we collected scrap papers on which student did work solving problems on multiple choice exams, we identified those students who drew the diagrams, and then we scored those free-body/force diagrams using the rubrics described above). We also found that students who draw diagrams correctly (scored a 2 and 3 on the free-body/force diagram rubric) are significantly more successful in obtaining the right answer for the problem. Lastly, we interviewed students to uncover their reasons for using free-body diagrams. We found that high achieving students used the diagrams to help solve the problems and as a tool to evaluate their work while low achieving students only use representations as aids in the problem-solving process. (See reference 16 for the details of the study).

4.2 Study of student acquisition of scientific abilities

We conducted several studies that investigated how students develop experiment-related scientific abilities in real time in ISLE instructional laboratories. The ISLE laboratories are naturally integrated in the learning process. In laboratories students design their own experiments without cookbook instructions but with the support of special guiding questions and self-assessment rubrics described above. An example of a laboratory handout is provided Appendix B.

The most important aspect of the ISLE laboratories is that students have to implement different scientific abilities, such as evaluating uncertainties and assumptions not because the lab handout requires those steps but because without them the students cannot solve the problem. For example, the students need to determine the specific heat of an object made of an unknown material. If they conduct only one experiment, there is no way to say whether the number they obtain makes any sense since there is no "accepted value". Therefore, the students need to design a second independent experiment and then make a decision on the value of the specific heat based on the assumptions in their mathematical procedure and the experimental uncertainties in their values.

In a typical laboratory, students conduct one or two experiments.

All of the experiments can be grouped into three big categories (according to their role in the ISLE cycle). The first type is observational experiment that takes place when students have to investigate a new phenomenon that they have not yet seen in large room meetings or problem solving sessions. When students design observational experiments, they need to figure out how to collect the data suggested by the laboratory handout and how to analyze the data to find patterns. For example, they need to find a pattern between the current through and potential difference across a resistor. The second type of experiments is testing experiment that students design when they need to test a hypothesis. This hypothesis is usually based on a pattern observed in a previous laboratory experiment or it is a hypothesis that students devised in other parts of the course prior to the laboratory. Sometimes they have to test a hypothesis that "a friend has devised" — these are usually based on known student ideas from the physics education research. For example, students need to test a hypothesis that magnetic poles are electrically charged. The third type is application experiment. This is experimental problem that requires students to design several experiments to determine the value of some physical quantity — such as the coefficient of friction between their shoe and the carpet. The application experiments, as their name suggests, are the experiments where students have to apply one or more concepts that they already know to solve the problem. The laboratory handout scaffolding questions and the rubrics are different for these three types of experiments. Appendix B shows an example of the laboratory handout for the first two types of experiments.

To study the development of abilities that students develop while designing and carrying out the above experiments abilities we collected and scored the lab reports of 60 students in an algebra-based introductory physics course at Rutgers University (enrollment of about 200 students) during one semester (the course followed ISLE). The details of the studies can be found in the following references (Etkina, Karelina & Ruibal-Villasenor, 2008; Etkina & Karelina, et.al., 2009; Karelina & Etkina, 2007). Here I provide the summary of our findings.

The research questions that we answered in the reported studies were: How long does it take for the majority of the students to develop different scientific abilities? Does this time depend on the ability? And are there any specific abilities that are especially difficult?

We investigated several abilities and their development over the course of one semester by scoring the lab reports of 60 students in the course Physics for the Sciences at Rutgers University using the rubrics described above. We found that at the beginning of the semester the majority of the students received the scores of 0 and 1 on the rubrics and as the semester progressed the scores increased. After week #5 students started showing significant improvement on some abilities (ability to design an experiment, ability to identify experimental uncertainties, ability to communicate) and by week 7–8 (this means that students had 7 to 8 3-hour laboratories and had to write 7 to 8 lab reports) over 80 % were receiving scores of 2 and 3 on the majority of the rubrics (including such ones as the ability to evaluate uncertainty, ability to recognize the difference between the hypothesis and the prediction, ability to identify assumptions, etc.). After week 8 the number of students receiving high scores stopped changing being settled around 80 %. The only ability that never reached 80 % of scores 2 and 3 and kept steadily improving was the ability to evaluate the effects of assumptions. We think that this finding can be explained by the fact that this particular ability depends on the knowledge of the relevant physics material more than any other abilities. These results have been repeated multiple times over the years and we find them to be very robust. Another robust finding (that persists in different universities) is student attitude towards such laboratories. As they differ drastically from traditional cook book labs to which students are accustomed, at the beginning of the semester they are lost and anxious, and do not know what to do or how to do it. However by about week 8 of the semester one can notice a significant shift in their behaviors. They become more relaxed and they know what is expected of them — they know what to do. The real changes come at the end of the semester when they not only know what to do but also how to do it. These three easily recognizable stages in student attitudes towards such design abs were first documented by X. Zou who implemented ISLE labs at the California State University, Chico but later we also observed them year after year at Rutgers.

4.3 Transfer of scientific abilities

After we found that students do indeed develop scientific abilities as scored by the rubrics when working on the physics design experiments we wanted to investigate whether they transfer these abilities to a different content area. The issue of transfer is extremely complicated and I will not delve here into the details of different models of transfer and how we set up the experiment to study one of the types of transfer in our case. All of the details are described in the paper by Etkina et.al, published in 2010 in the Journal of Learning Sciences (Etkina et.al., 2010). Here, again, I will briefly outline the structure of the study and summarize the findings.

Population: The study was conducted in the first (fall) semester the same course where we conducted the previous study, there were 193 students attending various activities varied through the semester. There were two 55-min lectures, one 80-min recitation, and a 3-hour lab per week. There were two midterm exams and one paper-and-pencil final exam and final lab exam. All students learned through the same ISLE approach in large room meetings and in smaller recitations. The lab sections were split into two groups: design labs (4 sections) and non-design labs (4 sections). Students registered for the sections in March of the previous academic year. In the previous years we found no difference in performance of lab sections on exams, thus we can assume that during the experimental year the student group distribution was random. During the semester, students were not informed about the study. At the end, we disclosed the procedure and students signed a consent form allowing us to use their work for research. We took precautions to ensure that the groups were equal in learning ability using Lawson's test of hypothetico-deductive reasoning in the first lab session (Lawson, 1978). Coletta and Philips (2005) found that student's learning gains are strongly correlated with their scores on this test. Our lab sections were statistically the same. To ensure that the treatment was the same too, we used the same three instructors to teach the labs. Two of the instructors taught one design and one non-design section and the third instructor taught two of each. All instructors were members of the PER group, highly skilled in the interactive teaching.

Experimental group: Design labs (4 sections): Students in the experimental group had *ISLE* design labs described above. They had to design their own experiments and use rubrics for self-assessment.

Control group: Non-design labs (4 lab sections): Students in the control group used the same equipment as in design labs and performed the same number (sometimes even more) experiments. The lab handouts guided them through the experimental procedure but not through the mathematics.

Assessment of student learning of physics and acquisition and transfer of scientific abilities: We assessed student learning by their performance three paper-and pencil course exams (2 midterms and one final) and on two transfer tasks. Course exams had a multiple-choice portion and an open-ended portion (3 problems per midterm and 5 on the final).

Transfer to Physics: To assess how students transfer scientific abilities to an unfamiliar physics content in the same functional context, we developed a lab task where both groups designed an experiment and wrote a lab report. In contrast to regular labs that students performed during semester, this particular task was identical for the experimental and the control groups. The task involved drag force in fluid dynamics. This physics content was not covered in the course. Students were provided some necessary and some redundant information in the lab handout and had access to textbooks and the Internet.

The students performed this task during the lab (3 hours) on week 13 of the semester. Prior to this, they performed 10 labs.

Transfer to Biology: The second transfer experiment involved a biology task that was given as the final lab exam for the course in week 14. Both the experimental and the control groups had to design an experiment to find the transpiration rate of a certain species of plant and subsequently to write a report detailing their experimental procedures, calculations and conclusions.

During the practical exam students in each lab section worked in the same group of three or four as they did during the semester. As during the semester, students submitted individual reports for grading.

When the exam was graded students from both groups received scores that reflected their performance relative to the standards for two different kinds of labs. After the semester was over, the researchers used the scientific abilities rubrics to code student work.

FINDINGS ACQUISITION OF NORMATIVE SCIENCE CONCEPTS

With regard to the normative science concepts that were assessed via multiple-choice and free-response exam questions and problems, students in the design and non-design groups performed similarly on both midterms and the final exam: Midterm Exam 1, $\mathbf{F}(1,182) = 0.25$, $\mathbf{p} = 0.62$; Midterm Exam 2, $\mathbf{F}(1,180) = 1.31$, $\mathbf{p} = 0.25$; final exam, $\mathbf{F}(1,180) = 0.45$, $\mathbf{p} = 0.502$ (to make three contrasts, we used the sequential Bonferroni correction, critical value of 0.017).

Scientific abilities rubrics: Physics Transfer task: Reading of the lab reports revealed the features that made a difference in the performance of two groups. The quantitative analysis of the lab reports supported the general impression on students' performance. There were significant differences in the lab reports of design students and non-design students. Design students demonstrated significantly better scientific abilities than the non-design students specifically on the following rubrics: *Evaluating the effect of assumptions* (fifty seven design students (more then 60 %) received score 2 or 3; not a single student in non-design section made an attempt to do this); *Evaluating effect of uncertainties:* (only 11 of non-design students (12 %) got score 2 or 3 while more then 50 % of design students evaluated the effect of experimental uncertainties in this lab. The difference between the groups is statistically significant (Chi-square$=$ 30, $p < 0.001$)); *Evaluating the result by means of an independent method* (about 64 of design students (72 %) got score 2 or 3, while in non-design sections only 38 students (43 %) did. The difference between the groups is statistically significant (Chi-square$=$ 16, $p < 0.001$)); *Communication* (more then 60 % of design students drew a picture while only 8 % of non-design students did. The difference in student scores on the communication is statistically significant (chi-square$=$ 60.6, $p < 0.001$)). In addition we found the differences in students use of force diagrams and overall consistency o representations with the design students significantly outperforming the non-design students.

We found very similar results for the biology task, design group students demonstrated the transfer of acquired scientific abilities significantly better than non-design students. The details of the analysis can be found in reference 18.

5 DISCUSSION

In my talk at the conference and here I attempted to show that inquiry-based instruction with proper scaffolding and formative assessment can be successful in helping students develop scientific habits of mind that are needed for the success in the 21st century. Examples of such habits of mind — scientific abilities — are the skills and procedure that are needed in all areas of future lives of our students and are called for by the documents guiding science education. We can help all students (not necessarily physics majors) develop such abilities and later these students also transfer those abilities to new content areas. Three things are important here:

1. ISLE is not an open inquiry-based curriculum that engages student in random investigations of phenomena with the hope of them finding out things on their own. It is a heavily scaffolded approach that encourages students to construct and test their own understanding through a series of carefully chosen experimental investigations supported with specific questions and self-assessment rubrics, aided by concrete representations.
2. It takes time for the students to develop those abilities (5–8 weeks), so we should not get discouraged when after a month of instruction our students still cannot design their own experiments or evaluate how the assumptions might affect the results of their calculations.
3. We should not be afraid that students will not learn the "right" physics if they design their won experiments and make mistakes. We found that engaging students in experimental design when they sometimes come up with "wrong" solutions and do not practice solving traditional physics problems does not hurt them in terms of the acquisition of normative physics knowledge. However, they benefit significantly in terms of persistence and ability to approach new problems as scientists.

APPENDIX 1

Examples of Multiple Representations activities:

Representing the problem situation in multiple ways: You are riding to the top floor of your residence hall. As the elevator approaches your floor, it slows to a stop. Construct a motion diagram and a free-body (force) diagram for the elevator [with you inside] as the object of interest as the elevator slows down to a stop.

Jeopardy problem: The mathematical expressions below could represent many physical situations. Invent one situation and describe it with words, with a force diagram, with a sketch, and with a motion diagram. The object moves vertically. We assume that $g = 10\ \mathrm{m/s^2} = 10\ \mathrm{N/kg}$.

$$\begin{aligned} -T + (1\,000\ \mathrm{kg})(10\ \mathrm{N/kg}) &= (1\,000\ \mathrm{kg})(2.0\ \mathrm{m/s^2}) \\ -0 + (-8.0\ \mathrm{m/s}) &= (2.0\ \mathrm{m/s^2})t \\ y &= (-8.0\ \mathrm{m/s})t + (1/2)(2.0\ \mathrm{m/s^2})t^2 \end{aligned}$$

APPENDIX 2

A laboratory handout with the examples of two different types of experiments:

Lab 3: The Electric Potential and Electric Currents

LEARNING GOALS OF THE LAB

1. Learn how to construct a working apparatus using a schematic picture.
2. Learn to fit functions to data in order to represent graphical patterns with mathematical expressions.

I. OBSERVATIONAL EXPERIMENT: DETERMINE A MATHEMATICAL RELATIONSHIP BETWEEN CURRENT THROUGH AND VOLTAGE ACROSS A RESISTOR

Design an experiment to determine a mathematical relationship between the current through a resistor and the voltage across that resistor. First you will design your experiment using the simulation from experiment II. Clear the simulation; then use it to build a circuit that will allow you to accomplish your goal.

To measure the current through the resistor using an ammeter, you need to let this current pass **through the ammeter**. To measure the voltage (potential difference) across the resistor using a voltmeter, you need to connect the voltmeter so **it measures the electric potential before and after the resistor**:

An ammeter and a voltmeter are available in the simulation by checking the appropriate checkboxes. Once you have built the circuit using the simulation, call your TA over and explain it to them. Also, explain what measurements you are going to make and how you will use them to accomplish your goal. Once you have done this, build your circuit using real equipment.

Available equipment: Voltage source resistor, 2 multimeters, connecting wires.

RUBRIC B: Ability to design and conduct an observational experiment

Scientific Ability		Missing	Inadequate	Needs some improvement	Adequate
B3	Is able to decide what physical quantities are to be measured and identify independent and dependent variables	The physical quantities are irrelevant.	Only some of the physical quantities are relevant.	The physical quantities are relevant. However, independent and dependent variables are not identified.	The physical quantities are relevant and independent and dependent variables are identified.
B7	Is able to identify a pattern in the data	No attempt is made to search for a pattern	The pattern described is irrelevant or inconsistent with the data	The pattern has minor errors or omissions	The patterns represents the relevant trend in the data

RUBRIC G: Ability to collect and analyze experimental data				
Scientific Ability	Missing	Inadequate	Needs some improvement	Adequate
G2 Is able to evaluate specifically how identified experimental uncertainties may affect the result	No attempt is made to evaluate experimental uncertainties.	An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect. Or only absolute uncertainties are mentioned. Or the final result does not take the uncertainty into the account.	The final result does take the identified uncertainties into account but is not correctly evaluated.	The experimental uncertainty of the final result is correctly evaluated.
G4 Is able to record and represent data in a meaningful way	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible.	All important data are present, but recorded in a way that requires some effort to comprehend.	All important data are present, organized, and recorded clearly.
G5 Is able to analyze data appropriately	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.

Include the following in your writeup:

a) Devise a procedure for your investigation and briefly describe your experimental design. Include a labeled sketch of your setup.

b) What important physical quantities change during the experiment? What are the independent and dependent variables in your experiment?

c) Build the circuit according to your picture. **Then, call your lab instructor over to check the circuit.** After you've done that, you can turn on the voltage source.

d) Record your data in an appropriate manner. Construct a graph. Think what mathematical functions may fit you data (Excel has features that let you explore how well different functions fit your data).

e) Find the SIMPLEST mathematical function that does fit your data. Think of uncertainties (error bars). Does the function you chose cross through the regions defined by the error bars?

f) Formulate a quantitative rule relating the current through a resistor to the voltage (potential difference) across the resistor.

II. TESTING EXPERIMENT: CURRENT-VOLTAGE DEPENDENCE

The goal of this experiment is to test whether the rule relating the current through a resistor and the voltage across resistor is applicable to a light bulb. Remember that the purpose of testing experiment is to reject, not to support the rule under test.

Available equipment: Voltage source (again, keep the voltage below 5 V), light bulb, resistors, 2 multimeters, connecting wires.

Write the following in your report:

a) State what rule you are testing.
b) Brainstorm the task and make a list of possible experiments whose outcome can be predicted with the help of the rule.
c) Briefly describe your chosen design. Include a labeled sketch.
d) **Use the rule being tested to make a prediction** about the outcome of the experiment.
e) Perform the experiment. Record the outcome.
f) Is the outcome consistent or inconsistent with the prediction? Explain in detail how you decided this.
g) Based on the prediction and the outcome of the experiment, what is your judgment about the rule being tested?
h) Ask your classmates in other lab groups about their results. Are they consistent with yours?

V. WHY DID WE DO THIS LAB?

a) Discuss how plotting the data in experiment III helped you identify the relationship between the current through the resistor and the voltage across it.
b) What other question/phenomena could you investigate using the available equipment from this lab?
c) Give an example of an experiment from your field of study where a pattern in data is used to construct a mathematical relationship.

POSTSCRIPT (OPTIONAL, AND REALLY JUST FOR YOUR AMUSEMENT): THE PLATYPUS

The platypus, a native of Australia, is an odd type of mammal called a monotreme. It has fur, webbed feet, and a bill like a duck. The young are born from eggs and although the mother produces milk for them she has no nursing organs we would recognize: milk seeps through a patch of skin on the mother's underside.

The platypus lives in freshwater streams and eats crustaceans, insects, and small fish. The platypus is a beaver-sized animal and must need to eat a lot of bugs, but its small and beady eyes don't look very helpful for finding its prey among the rocks and sand at the bottom of a muddy creek.

The secret to this animal's success is actually in its bizarre beak. This contains millions of electroreceptive cells that can detect the incredibly minute electric field that is generated by the neurons of bugs and shrimp!

Professor Uwe Proske of Monash University reports that about two-thirds of the sensory area of a platypus's brain is connected to the beak. The system seems to have evolved completely independently from similar electroreceptive systems in fish such as sharks.

However it operates, and however it evolved, it seems to work remarkably well. The platypus manages to capture half its body weight in food every night.

REFERENCES

Aikenhead, G. S. (2005). Science-Based Occupations and Science Curriculum: Concepts of Evidence. *Science Education*, 89, 242–275.

Chin, P., Munby, H., & Hutchinson, N. L., et.al. (2004). Where's the science? Understanding the form and function of workplace science. In E. Scanlon, P. Murphy, J. Thomas, & A. E. Whitelegg (Eds.), *Reconsidering science learning*, (118–134), London: Routledge Falmer.

Coles, M. (1997). What does industry want from science education? In K. Colhoun, R. Panwar, & S. Shrum (Eds.), *Proceedings of the 8th symposium of IOSTE* (292–300). Edmonton: Faculty of Education, University of Alberta.

Coletta, V. P. & Phillips, J. A. (2005). Interpreting FCI scores: Normalized gain, preinstruction scores, & scientific reasoning ability. *American Journal Physics*, 73(12), 1172–1182.

Czujko, R. (1997). The Physics Bachelors as a Passport to the Workplace: Recent Research Results in The Changing Role of Physics Departments in Modern Universities. E. F. Redish & J. S. Rigden, (Eds). *AIP Conf. Proc.* 399, Woodbury, NY.

Duggan, S. & Gott, R. (2002). What sort of science education do we really need? *International Journal of Science Education*, 24, 661–679.

Educating the Engineer of 2020: Adapting Engineering Education to the New Century, (2005). The National Academies Press, N.W., Washington. Available at http://nap.edu/catolog/11338.html

Etkina, E., Brookes, D. & Van Heuvelen, A. (2013). *Instructor Guide for College Physics.* San Francisco, CA: Pearson, 2013.

Etkina, E., Gentile, M. & Van Heuvelen, A. (2013a). *College Physics.* San Francisco, CA: Pearson.

Etkina, E., Gentile, M. & Van Heuvelen, A. (2013b). *The Physics Active Learning Guide* (2nd ed.). San Francisco, CA: Pearson.

Etkina, E., Karelina, A. & Ruibal-Villasenor, M. (2008). How long does it take? A study of student acquisition of scientific abilities. *Physical Review, Special Topics, Physics Education Research*, 4, 020108; 9.

Etkina, E. & Karelina, A., et.al. (2009). Using action research to improve learning and formative assessment to conduct research. *Physical Review. Special Topics, Physics Education Research*, 5, 010109; 14.

Etkina, E., Karelina, A. & Ruibal-Villasenor, M., et.al. (2010). Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories. *Journal of the Learning Sciences*, 19, 1, 54–98.

Etkina, E., Planinšič, G. & Vollmer, M. (2013). A simple optics experiment to engage students in scientific inquiry. *American Journal of Physics*, 81 (11), 815–822.

Etkina, E., Van Heuvelen, A. & White-Brahmia, S., et.al. (2006). Developing and assessing student scientific abilities. *Physical Review. Special Topics, Physics Education Research.* 2, 020103.

Etkina, E. & Van Heuvelen, A. (2007). Investigative Science Learning Environment — A Science Process Approach to Learning Physics, in E. F. Redish, P. Cooney (Eds.), *Research Based Reform of University Physics*, (AAPT). Available at http://per-central.org/per_reviews/media/volume1/ISLE-2007.pdf

Gott, R., Duggan, S. & Johnson, P. (1999). What do practicing applied scientists do and what are the implications for science education? *Research in Science & Technological Education*, 17, 97–107.

Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop, (2003). The National Academies Press, N.W., Washington. Available at http://darwin.nap.edu/books/0309089298/html

Karelina, A. & Etkina, E. (2007). Acting like a physicist: Student approach study to experimental design. *Physical Review, Special Topics, Physics Education Research*, 3, 020106.

Lawson, A. E. (1978). The development and validation of a classroom test of formal reasoning. *Journal of Research in Science Teaching*, 15(1), 11–24.

Lottero-Perdue, E., & Brickhouse, N. W. (2002). Learning on the job: The acquisition of scientific competence. *Science Education*, 86, 756–782.

Next Generation Science Standards, (2013). Available at http://www.nextgenscience.org/next-generation-science-standards Rosengrant, D., Van Heuvelen, A. & Etkina, E. (2009). Do students use and understand free body diagrams? *Physical Review, Special Topics, Physics Education Research*, 5, 010108.

Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2009). Do students use and understand free body diagrams? Physical Review, Special Topics, Physics Education Research, 5, 010108.

EUGENIA ETKINA[*]
Rutgers University, NJ USA

---

[*] Although the paper bears my name only, this work is based on the collaborative efforts of many people, such as A. Van Heuvelen, A. Karelina, M. Ruibal-Villasenhor, C. Hmelo-Silver, R. Jordan, S. Murthy, D. Brookes, and M. Gentile.

Scientia in educatione 8(Special Issue), 2017
p. 22–41
ISSN 1804-7106

Sport and Physics

Leopold Mathelitsch

Abstract

The combination of sport and physics offers several attractive ingredients for teaching physics, at primary, secondary, as well as university level. These cover topics like interdisciplinary teaching, sports activities as physics experiments, video analysis or modeling. A variety of examples are presented that should act as stimulus, accompanied by a list of references that should support the implementation of sport topics into physics teaching.

Key words: sport, physics teaching, video analysis, modelling.

INTRODUCTION

Physics and sports seem to have not much in common, at least in school teaching, where they are very disconnected subjects: disparate with respect to contents, but also to location, kind of activities or interest of students. Despite this distance, one can find good reasons to bring these two subjects of school education closer to each other: different kinds of sports could serve as examples for applying physical laws; sports activities by students can be seen as physics experiments including quantitative exploration; modern technology offers the possibility to visualize and analyze movements. But this proposal should not be seen as one-directional in that sport comes into the physics class, it should be a challenge for a balanced cooperation. Let's take the location as an example: a physics class can take place in the swimming pool or gym, a sport class can experiment in the physics lab. This implies also a strong collaboration of the teachers: a physics teacher needs the support of the sports teacher while students perform activities; on the other hand, the physics teacher can take over the biomechanical part of sports training. A realization of these goals would lead to a true interdisciplinary teaching, written down in many school curricula around the world, but rarely executed in this sense, also around the world.

The aim of this paper is to illustrate and exemplify the above statements in more detail. The next chapter discusses didactic reasons why a connection of sports and physics could be of mutual benefit to both school subjects. Sometimes teachers claim that they do not find proper material, in particular adapted for use in schools. Therefore special focus is laid on an extensive list of references. The main part of this article, however, consists of a collection of examples that should illustrate and support the theoretical claims.

SPORTS AND PHYSICS

The link between sports and physics is very important in the professional sport business. In order to improve training techniques and therewith the achievement of athletes, physics enters on several occasions: it plays an important role in the development of new material, it is part of the technological equipment necessary for data taking and analyzing, and it is the basis for biomechanical models trying to understand human performance. Therefore many research institutes have been established, and scientific results are published in corresponding journals.

With regard to school education, the connection of sports and physics is much less obvious. In fact, they represent two subjects that are very often diametric on the scale of attractiveness. Nevertheless, several arguments can be found suggesting to bridge these two sciences even at school level. In the following we will discuss some of them.

VISUALIZATION

Observation is a discipline in physics education which is not valued and activated to the extent it deserves. Students should learn to observe carefully and also to describe what they see: on the one hand, it is amazing how varying the descriptions of the same action are given by different students; on the other hand, a detailed description leads very often to the question "why", and consequently to an attempt for explanation. There could be no better starting point for a topic in physics as when the students ask for an explanation.

Sports actions have one disadvantage in this respect that one cannot observe them easily in reality in a class room. But there exist videos of all kinds of sports actions with the benefit that one can repeat them as often as wanted. And sports actions can be very complex (for example the rotations of a diver off a high board), so that even the task of describing the movement can be demanding to students.

In addition, sports actions can run very fast so that even repetitions do not help in recognizing what is going on. For this reason, slow motion has been used for a long time in analysing such actions. Fortunately, the technological progress made it possible that high-speed cameras are available at such good quality and low price that they became a useful equipment in school labs (Heck & Uylings, 2010). An example of such visualization is given in the next chapter treating collisions of billiard balls.

VIDEO ANALYSIS

The next step beyond visualization is a quantitative exploration of an action, very often by video analysis. Several programs for such an analysis have been developed with special emphasis on applications in physics education. Some of them are freely available (Viana, Tracker), some are commercial ones (Logger Pro, Coach). Most of them are very user/student friendly, allowing for tracking certain elements of the action, either by hand or automatically, and enabling easy data taking and processing. Another feature allows for adding information in the video (e.g. velocity or force vectors) leading to a more explanatory presentation (Measure Dynamics).

Video analysis is a very important tool in sports research where simultaneous videos of several cameras can lead to a three-dimensional reconstruction of the event. But even with one camera, results can be obtained of high quality, when the action takes place in a plane like the movement of some sports equipment (ball, spear, ...). An attractive feature for school physics is the fact that students can take the video by themselves or play the actor (for example executing a penalty in soccer) and they analyze and calculate their own performance (e.g. motion and speed of the ball).

EXPERIMENTS

Most of the attraction of sports classes is based on activity: students are not only allowed but encouraged to move, to exercise, to compete. In the physics class, experiments are usually the only possibility for physical activity, and this does not happen too often, in general. Experiments with sports actions could be an interesting and challenging combination of activity and quantitative exploration — both for students and teachers. This can be performed in the class room (a simple determination of the force of the own legs or the measurement of the coefficient of restitution for different balls), in the physics lab (measurement of the properties of a tennis racquet) or out of school (in a billiard saloon).

Experiments in the physics lab are often guided by clear descriptions what the students should do with which apparatus. Sports experiments can be posed as very open tasks, the students could suggest what they want to explore, they should propose and design the experiment. For example, several possibilities exist to measure the coefficient of restitution of a ball; the results of different experiments can be compared and the quality and accuracy of the different methods can be discussed.

MODELS

Modeling is an important ingredient of scientific research. Physics curricula demand that modeling should also be part of the education of students, even at secondary level (Guttersrud, 2008). A GIREP conference was dedicated entirely to "Modeling in Physics and Physics Education" (van den Berg, Ellermeijer & Slooten, 2008). Modeling tools are sometimes even implemented in video analysis software (van Buuren, Uylings & Ellermeijer, 2010).

Working with ideal situations (a mass glides without friction along an inclined plane), the students do not see the value of and necessity for models. Sports actions, in particular when the human body is involved, are very complex. In order to describe and explain them, students see immediately that they have to make approximations, simplifications, and therefore have to work with more or less sophisticated models of the real situation.

INTEREST

Several studies have shown that physics is not a popular school subject. In a representative study in the province of Styria (Austria) more than one thousand of students aged 10 to 14 were asked which school subjects they like and in which they are interested (Lex & Gunacker, 1998). The data reveal that the interest is high when the students start with this school type, but that it drops immediately after. The bad message is not only the decrease, but that it happens during the first year of physics teaching.

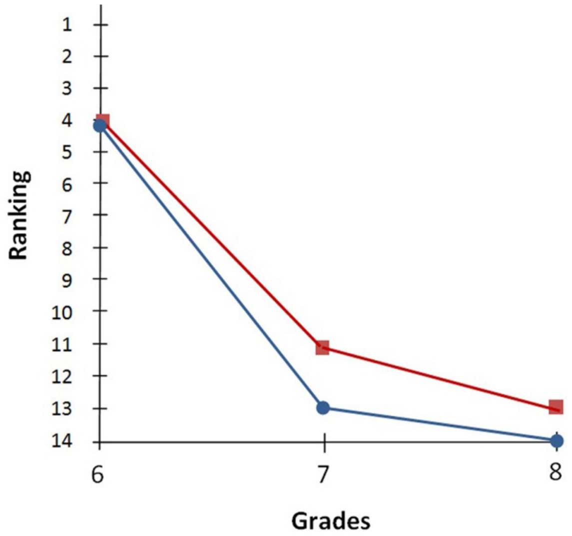


Figure 1: Interest in (blue circles) and popularity of (red squares) the subject physics (Lex & Gunacker, 1998)

Another study by a German group was much more detailed (Häußler et al., 1996). Figure 2 shows three groups of students, those interested in physics (A), a second group with medium interest (B) and a third one which indicated no interest (C) — this definition is a bit simplified compared to the original article (Häußler et al., 1996). The students were asked in which components of physics their interest lies, in which field they want to learn more: quantitative physics (brown columns), qualitative physics (green), functioning of technical instruments (red), natural phenomena (yellow), and physics and society (blue). The profile of the three groups

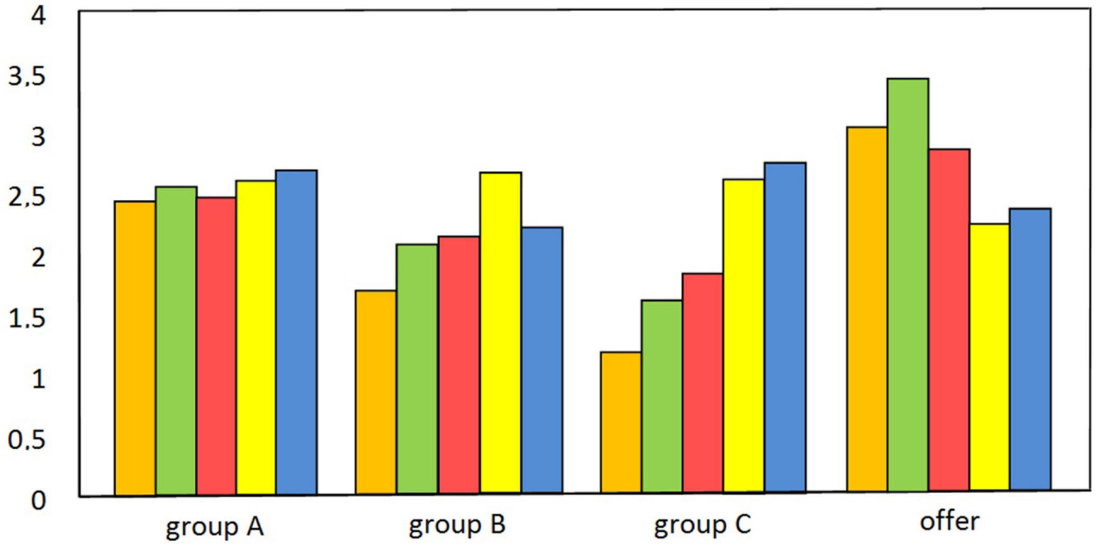


Figure 2: Interest profile of students (description see text) (adapted from Häußler et al., 1996)

is given in the left graphs. And on the very right side the actual offer is shown, as indicated by the students. A discrepancy is obvious and also disturbing. I do not advocate here that the desires of students should be the guidelines for teaching, but, speaking in economic terms, a company is not well advised when it produces against the market (group B and C make about 80 percent of the students).

Investigations revealed what particular topic and content are of special interest to students (Trumper, 2006). Not surprisingly, a gender difference shows up: roughly speaking, boys have a tendency to the technological side of physics, whereas girls are interested in those fields that are more related to the human being (biophysics, medicine, society) (Häußler & Hoffmann, 2000). Sports falls into both of the above categories, again with some differentiation — boys are more fond of soccer, motor sports, girls more of gymnastics, Nordic walking and related activities. But in general, topics of sport are on the positive side of the interest for the majority of students and could therefore serve the purpose to make physics more attractive to them.

LITERATURE

Literature about the combination of sports and physics can be divided into specific groups. Research papers on the different aspects of biomechanics and related topics fill by far the largest area. I do not even want to try listing the names of journals dedicated to these topics, since they are such a great many. Above all, the articles naturally are so specialized that a transfer to educational purposes is very often difficult to make.

Journals like American Journal of Physics or European Journal of Physics aim at a broader audience, and teachers of physics are an intended target group. The articles therefore give a wider view on a topic. And a noticeable number of articles belong to sports and physics. Therefore a literature research in both journals is a good starting point in looking for profound information on physical explanations of sports topics. A Resource Letter has been compiled in American Journal of Physics with many references to articles and books ordered along sports topics (Frohlich, 2011). The journal Physics World in 2012 dedicated an entire issue to the topic "Physics and Sport" (Physics World, July 2012).

A gold mine, not only with regard to educational purposes, are books, entitled "Physics and . . . " giving a broad but profound view on the sportive and the physical sides of a special kind of sport: "The Physics of Baseball" (Adair, 2002; Cross, 2011), "The Physics of Basketball" (Fontanella, 2006), "The Physics and the Art of Dance" (Laws, 2002), "The Physics of Golf" (Jorgensen, 1999), "Physics of Hockey" (Haché, 2002), "Physics of Sailing" (Kimball, 2010), "Physics of Skiing. Skiing at the Triple Point" (Lind & Sanders, 1996), "The Science of Soccer" (Wesson, 2002), and similarly "Bicycling Science" (Wilson, 2004), "Gliding for Gold" (Denny, 2011), "The Mathematics of Projectiles in Sport" (de Mestre, 1990), "Golf Balls, Boomerangs and Asteroids" (Kaye, 1996). I apologize for having missed some discipline or book. Equally important are books that give an overview like "The Physics of Sports" (Armenti, 1992), "An Introduction to the Physics of Sports" (Spathopoulos, 2013),"The Dynamics of Sports: Why That's the Way the Ball Bounces" (Griffing, 2000), or "Gold Medal Physics. The Science of Sports" (Goff, 2010).

Less common are articles that are directed mainly to the implementation into physics education at high school level. "The Physics Teacher" or "Physics Education", for example, act as forum for such publications. "Sports Science" (Wiese, 2002) is a booklet dedicated to a young audience. Finally, I would like to point to a special project in the UK called "E-Learning in Physical Science through Sport — ELPSS" within the National Teaching Fellowship Scheme (Lambourne, 2014). A collection of so-called reusable learning objects has been developed with a mixture of videos, information and tasks; to my opinion an excellent material on problem-based learning applying sport examples.

Because of the readership of this proceedings, a constraint was set on English literature and no material in other languages was included (not even mine).

Examples

This chapter contains a collection of examples, correlated only by the combination physics and sports exhibiting the many facets of this topic. Most of the examples have been tested in school practice.

Billiard

"Follow shot" is a special action in billiards: the cue ball hits an object ball centrally and then runs after the object ball. In real time one does not recognize what happens in detail. Watching this action in slow motion, however, gives a clearer picture and students can figure out with the naked eye what's going on (Figure 3). The cue ball is hit on the upper end, therefore it gets speed and rotation in form of top spin (1). Linear momentum is conserved during the collision. Since the two balls have the same mass, the object ball gets the full velocity and the cue ball stops and stays at rest (2). The rotation of the cue ball cannot be transferred to the object ball, because the interaction time is very short and almost no friction works between the balls. Therefore, the rotation stays in the cue ball, it turns on the spot (3). But friction with the fabric causes the cue ball finally to move in the same direction as the object ball (4).

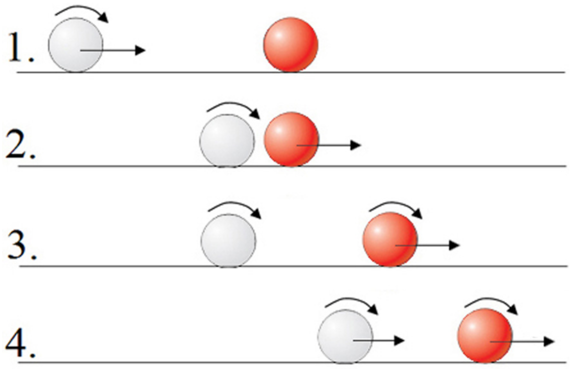


Figure 3: Follow shot (from Mathelitsch & Thaller, 2008: p. 98)

There exists also the possibility that the cue ball comes back: the player has to hit the ball below the middle and gives it a slice. But this is more difficult, there is the danger to damage the green fabric with the queue and one should not propose this action to students who are playing billiard for the first time.

When the object ball is not hit centrally, the two balls depart always with an angle of 90 degrees between them (Figure 4). Students have problems to believe that this angle is independent of how close to the center or how soft the two balls touch. Basic mathematics should persuade them.

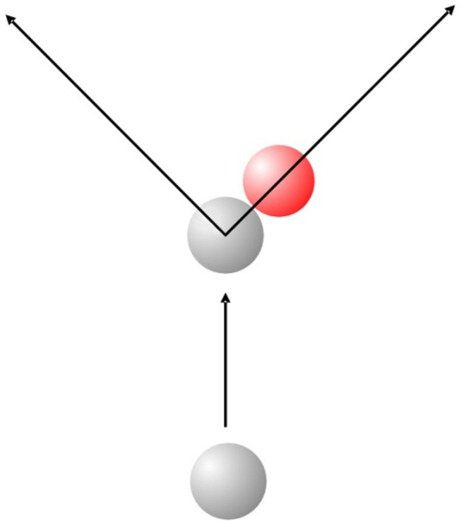


Figure 4: Non-central collision (adapted from Mathelitsch & Thaller, 2008: p. 99)

Conservation of energy and momentum leads to the following equations

$$\frac{1}{2}m \cdot V^2 = \frac{1}{2}m \cdot v_1^2 + \frac{1}{2}m \cdot v_2^2$$
$$m \cdot \vec{V} = m \cdot \vec{v}_1 + m \cdot \vec{v}_2$$

Division by the mass m and quadrature of the second equations yields

$$V^2 = v_1^2 + v_2^2$$
$$V^2 = v_1^2 + 2\vec{v}_1 \cdot \vec{v}_2 + v_2^2$$

Subtraction of the two lines leads to the final result

$$\vec{v}_1 \cdot \vec{v}_2 = 0.$$

That means that the angle between the two velocities after the collision has to and will always be 90 degrees.

This is not only a nice example for physics, it would also fit perfectly into the mathematics class after the introduction of the scalar product.

HIGH JUMP

An important parameter in jumping wide or high is the force of the legs. This force can be measured and calculated by a simple school experiment, at least approximately (Figure 5). The student stands towards a wall, hands upright, and makes a mark with the tips of the fingers. Then he bends the knee, makes again a mark and jumps as high as possible to put another mark. This is easier said than done, in particular the first part. How deep should one bend the knees? If it is not deep enough or too deep, the jump will not be maximal. Therefore the students first have to find out their optimal bending position.

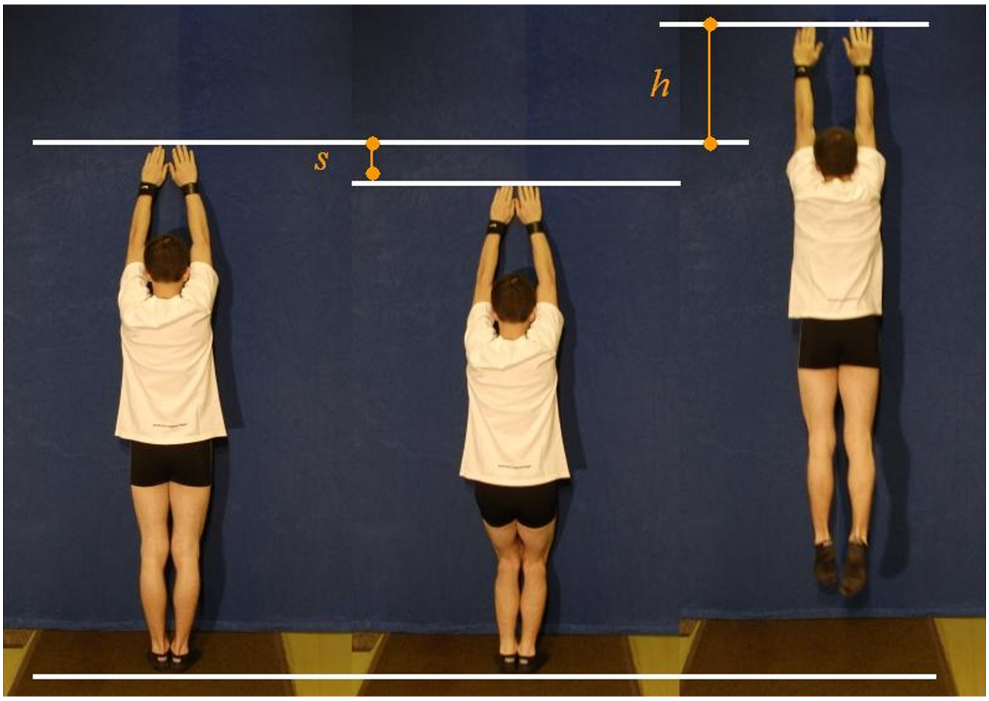


Figure 5: Determining the force of the legs (from Mathelitsch & Thaller, 2008: p. 57)

The force of the legs F_L is applied along the path s, the distance between the lowest point and the take off, leading to an energy

$$E = F_L \cdot s.$$

This energy is transferred to potential energy by lifting the body from the lowest to the highest position, i.e. along the distance $s + h$

$$E = m \cdot g \cdot (s + h).$$

Equating these equations yields an expression for the force of the legs F_L.

$$F_L = m \cdot g \cdot \frac{s + h}{s}.$$

The next example will be somewhat unrealistic, namely jumping on the Moon (Thaller, 2003). How high would one jump on the Moon? I will use this question as an example for applying different models.

The first model is based on the assumption that the jump-off velocity is the same on Earth and on Moon. With a given jump-off velocity v, conservation of energy

$$\frac{1}{2}m \cdot v^2 = m \cdot g \cdot h$$

results in a jumping height of

$$h = \frac{v^2}{2g}.$$

Since the gravitational force is only one sixth compared to that on Earth, it gives the result

$$h^{\text{Moon}} = 6 \cdot h^{\text{Earth}},$$

i.e., one jumps six times higher on the Moon as compared to Earth. This calculation and result can be found in many text books.

But one could also imply the assumption that the force of the legs is the same on Earth and on Moon. The accelerating force F is the difference of the force of the legs F_L and the gravitational force F_G

$$F = m \cdot a = F_L - F_G.$$

How strong is the force of the legs? A reasonable assumption is two times the own weight, since one can carry another person on the shoulders. By this, the accelerating forces on Earth and on Moon are

$$F^{\text{Earth}} = m \cdot g, \qquad F^{\text{Moon}} = \frac{11}{6} \cdot m \cdot g.$$

This leads to the fact that the jump-off velocities are not the same on Moon and on Earth

$$v_{Ab}^{\text{Moon}} = \sqrt{\frac{11}{6}} \cdot v_{Ab}^{\text{Earth}},$$

but differ by approximately 50 %. Inserting this in the equation for the jumping height from above gives the result

$$h^{\text{Moon}} = 11 \cdot h^{\text{Earth}}.$$

One jumps eleven times higher on the Moon than on Earth! This is almost twice as much as with the first model. So, which assumption or calculation is correct?

To answer this question we will look at a biomechanical model for jumping (Thaller, 2003). The main ingredient is how a muscle works. Contrary to a common belief a muscle does not function like a spring and would therefore obey a law similar to Hooke's law. Quite differently, the force of a muscle F_M is inversely proportional to its speed v

$$F_M = \frac{c}{v + b} - a$$

where a, b, c are parameters that can vary from person to person. Trying to shift a fixed hindrance exerts more force in the muscle as when the hindrance is moving. Applying this so-called Hill equation, a refined calculation yields the following result (Thaller, 2003)

$$h^{\text{Moon}} = 10.5 \cdot h^{\text{Earth}}.$$

The jumping height on Moon is about 10.5 time as great as on Earth. So, our second model was by far more realistic than the first one.

But men were already on Moon and jumped. Looking at videos, one can recognize only a mingy, a very meager jump. Why didn't John Young go up like hell? First of all, he had some extra weight in his backpack. Secondly, he was afraid of falling. But the main reason was that he was stuck in his space-suit and could barely move.

BOUNCING BALL

In many ball games, the contact of the ball with some surrounding, racket, floor, wall, basket, concrete layer, is essential. One parameter to characterize such a contact is the so-called coefficient of restitution e. It is defined as the ratio of the velocity after the bounce v_2 relative to the speed before the contact v_1:

$$e = \frac{v_2}{v_1}.$$

Since the velocity, in the ideal case of only gravitational forces, is connected in a straightforward way with the height, which the ball descends (h_1) and ascends (h_2), the coefficient of restitution can also be expressed in terms of distances

$$e = \sqrt{\frac{h_2}{h_1}}.$$

It is a motivating and for many students also demanding task to determine the coefficient of restitution for several sport balls to a certain accuracy. Since several possibilities can be found to measure the speeds and distances, different groups of students can challenge each other with the quality of their result. A golf ball should not be missing in the assortment of balls, since it is always a surprise for the students how reflective this ball is on a hard surface.

One suggestion by students very often is to use sensors and computers for the determination of the parameters of the movement of the ball. Such an analysis cannot only be used for the measurement of distances and speeds, it can also be extended to a discussion about energies (Turner & Ellis, 1999). Figs. 6–9 show such a series of investigations.

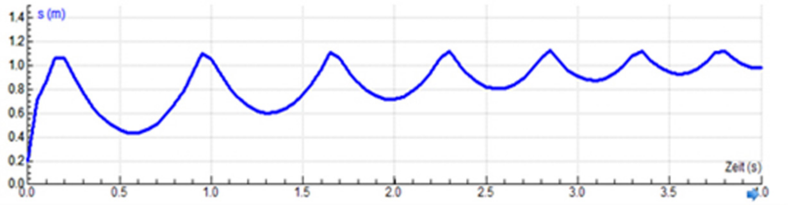


Figure 6: Ball bouncing several times on the floor

The ball is mounted at a certain height and the ball is first located a small distance below the sensor and then falls down to the floor and bounces. The data provide for a diagram like in Figure 6. This figure is often unfamiliar to the students, since it differs from the usual one in text books, where the floor is taken as center of reference. Therefore they have first to change the frame of reference (Figure 7, red curve).

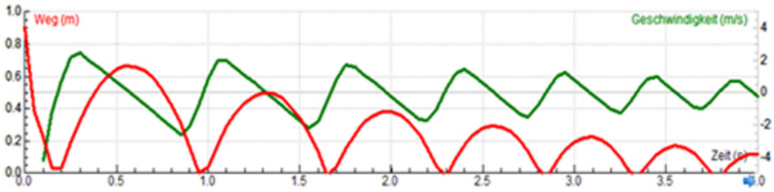


Figure 7: Distance of a bouncing ball relative to the floor (red curve) and corresponding velocity (green curve)

It is a real challenge to the students (sometimes up to college) to determine the velocity out of the data on the distance (Figure 7, green curve). And sometimes one has to help with hints like “At which moments is the speed zero?”, “At which is it maximal?”, “What does a negative velocity mean?”

The next logical step is to calculate the potential and kinetic energies of the ball (Figure 8). Again, the quadrature of the speed is not always a straightforward task for students.

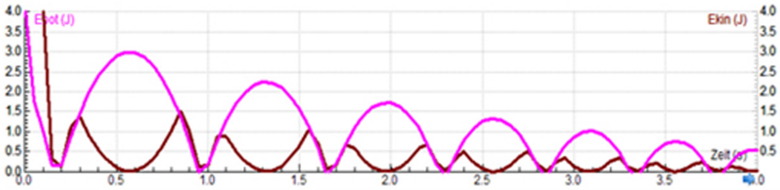


Figure 8: Potential (pink curve) and kinetic energy (brown curve) of the bouncing ball

Addition of both curves gives the total energy of the ball (Figure 9). It is clear that practically no energy is dissipated while the ball is in the air, but that the ball loses almost all of its energy during contact with the floor.

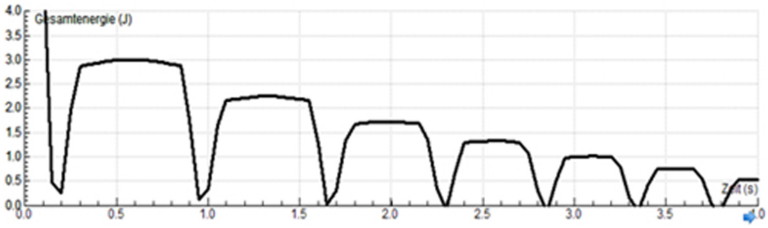


Figure 9: Total energy of the bouncing ball

The figures were produced by a software connected to data analysis (in this case Coach). But I would advise that the students should start and try to make their own figures by hand. Of course it will not be perfect, but it needs an understanding of the kinematic connections that are not always clear to the students.

TENNIS

In this part I will concentrate on the interaction of a tennis ball with the racket (Duenbostl, Mathelitsch & Oudin, 1996).

First the elasticity of the frame of a racket was measured. The racket was clamped on the handle and different weights were attached on the frame. Figure 10 shows the deviation of the frame relative to the weight. The relation is nearly a straight line, therefore Hooke's law can be applied and the oscillation time T can be calculated

$$T = 2\pi\sqrt{\frac{m}{k}}.$$

The constant k can be taken from the slope of the line in Figure 10 ($k = 10$ kN/m). But which value should one insert for the mass? This is not an easy question since the racket was clamped on one side — we took half of the mass of the racket ($m = 0.16$ kg). This leads to an oscillation time of $T_{\mathrm{frame}} = 25$ ms.

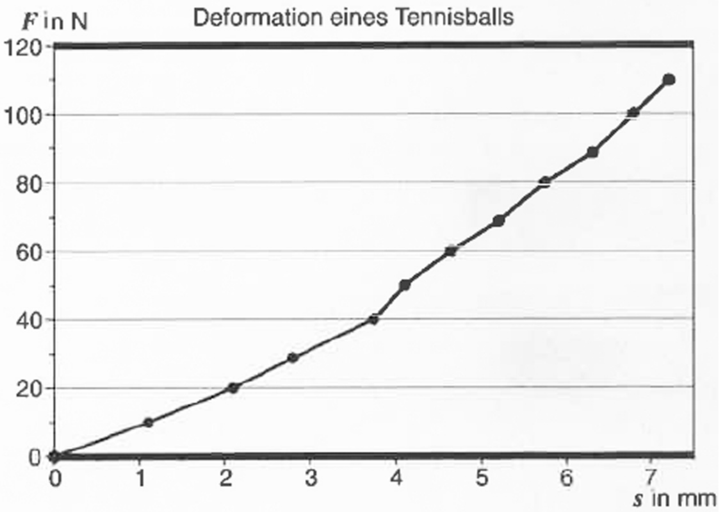


Figure 10: Deviation of the frame of a racket due to different masses attached (from Duenbostl, Mathelitsch & Oudin, 1996)

But we did not feel safe with this measurement, therefore we applied a different method: Strain gauges were glued to the racket and the resulting voltages were measured. The outcome can be seen in Figure 11. The nice oscillation curve confirms that Hooke's law is valid and also the oscillation time of $T_{\mathrm{frame}} = 30$ ms is not too far off the result from before.

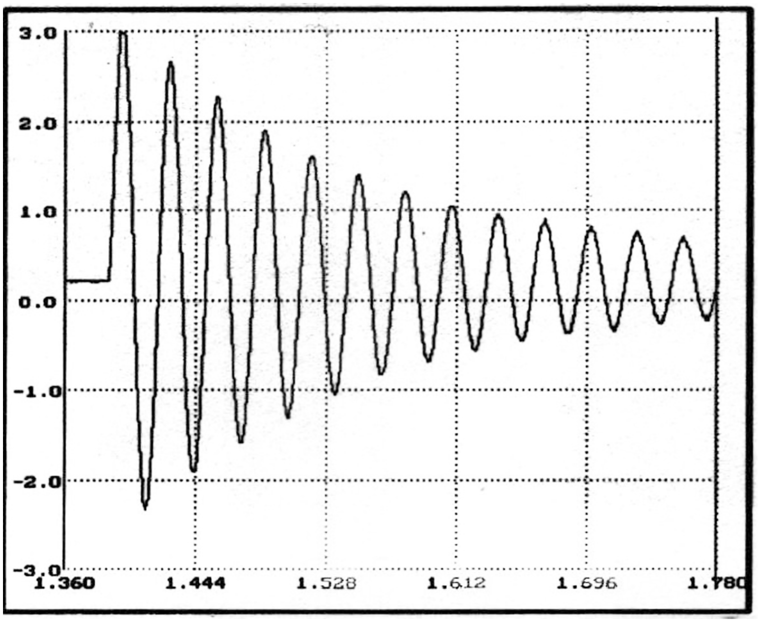


Figure 11: Oscillations of the frame of a racket (from Duenbostl, Mathelitsch & Oudin, 1996)

Next we measured the oscillation of the ball. Again we put weight on it and measured the deflection. The data (Figure 12) do not show such a straight line as before, but in first approximation we take it as straight. In this case the mass of the ball is easy to determine ($m = 0.058$ kg) and with $k = 15$ kN/m an oscillation time of $T_{\text{ball}} = 12$ ms results.

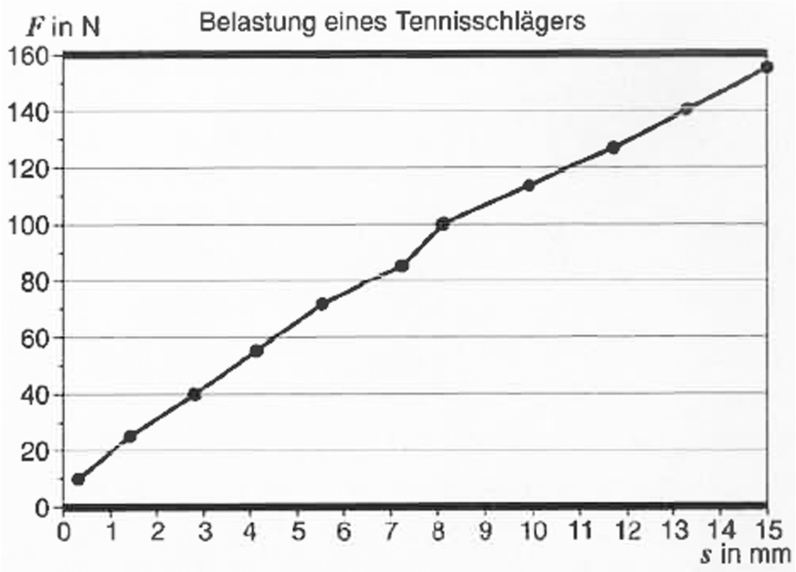


Figure 12: Depression of a ball due to different weights (from Duenbostl, Mathelitsch & Oudin, 1996)

But this does not fit to the first value: The ball hits the racket, it bends back, then forward, but at that time the ball is already off the racket. The energy of the racket is not transferred to the ball, it is wasted energy. But how does the ball get its great speed? There is another oscillating element involved, the strings. This measurement is not easy since the amplitudes are very small, much smaller than the amplitude of the racket itself. We put a clamp on the racket frame and attached a Hall sensor. A small magnet with little weight was glued to the string. The outcome can be seen in Figure 13.

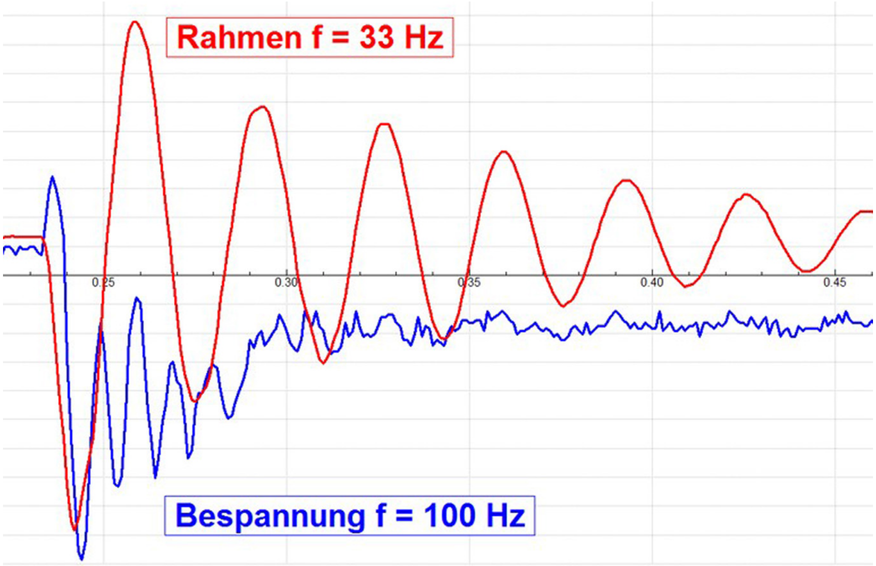


Figure 13: Oscillation of the frame (red curve) and of the strings (blue curve) (adapted from Mathelitsch & Thaller, 2008: p. 88)

The oscillation time of the strings of $T_{\text{string}} = 10$ ms fits perfectly to the oscillation time of the ball. So, the ball gets most of its energy from the strings, some from the ball itself. The swing of the frame is wasted energy. Therefore the manufacturer tries to make the racket as stiff as possible. In former times several layers of wood were glued together in a refined manner for this purpose. But these rackets had to be small, larger ones would have been too heavy. With new materials, it was possible to make larger rackets, stiff and light.

SOCCER

An English mathematician, Jack Dowie, has found some statistical correlations in scores of football teams (Dowie, 1981). And then he made an astonishing approach: He compared football to radioactive decay. If a large radioactive probe has a certain decay rate, let's say two decays in one minute, then, in the average, two nuclei will decay per minute. But one does not know how many will decay in the next minute, it could be none, one, two, three, … But physicists know the probability that zero, one, two, three decays will happen very well — it is given by the Poisson distribution

$$P_m(a) = \frac{a^m}{m!}\mathrm{e}^{-a}.$$

$P_m(a)$ is the probability that m decays will occur with a being the average decays.

The analogy with soccer goes as follows: A soccer team has a certain strength a, for example measured by the average number of goals per match it has scored in the past months. One does not know the score for the next game m, but taking the model of Dowie, one can calculate the probability of the number of goals according to the Poisson distribution. Given a strength of two goals, then the percentage for zero goal is 13.5 %, for one and two goals it is 27 %, for three goals 18 % and so on. And one can determine probabilities for results of matches. If both teams have the same strength of 2 goals per match, the probability for 0 : 0 is 1.8 %, it is 7.3 % for 1 : 1, 2 : 1 and so on. With this model Dowie calculated past results of the English Premier Division, with good agreement. We repeated the calculation with the example of the German Bundesliga (Mathelitsch & Thaller, 2006), and the result was similarly good, as can be seen in Figure 14. Students can repeat this calculation with their favorite team and can "predict" the result of the next game. This should also create some feeling of statistical results, which is difficult anyway for young and also older people.

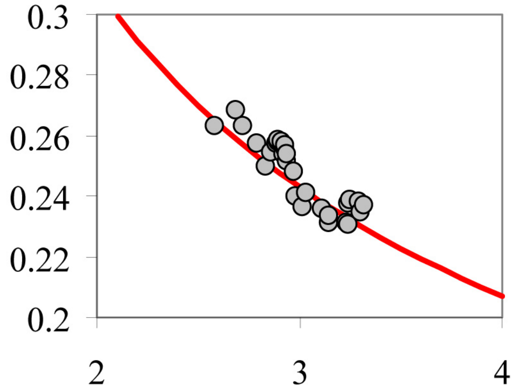


Figure 14: Results of the German Bundesliga (circles) compared to the statistical model (line). (From Mathelitsch, Thaller (2006) modified)

Students are not always impressed and convinced by the arguments above. Out of experience, the following points count more: One can bet on the results of soccer games (in many countries called Toto). But this resembles very much a typical gamble of luck (Lotto). And it has to be — otherwise experts of soccer would make a fortune by betting. In soccer, a third-class team can win against a first-class team. This does not happen very often in other kinds of sports, and it was calculated that the portion of chance in football is the highest of all kinds of sports-games (Ben-Naim, Vazquez & Redner, 2007).

The reason for this strange behavior is simple — it is the low number of goals. Let's assume that team A is twice as strong as team B (such a big difference is very unlikely in a certain league). In this case, the chance for the next goal is 2/3 for team A and 1/3 for team B. Will there be just one goal in the game, which often happens, the chance for team B to win is 33 %, which is not small.

RECORDS

Very fascinating for athletes, as well as the observing audience, are records, notably world records (Gembris, Taylor & Suter, 2002). World records will always be broken, even if material, training, ability of athletes would not change (Haake, 2012). Athletes, as all other living creatures, obey a statistical distribution with respect to different features. Figure 15 shows the example of the strength of a muscle; the sample consists of sports students, therefore the distribution is not symmetric. Therefore one does only have to wait long, and one athlete will come up whose features are more on the edge of the distribution — and he/she will break the record. In addition, material and training improve, and therefore new records are even more likely to occur.

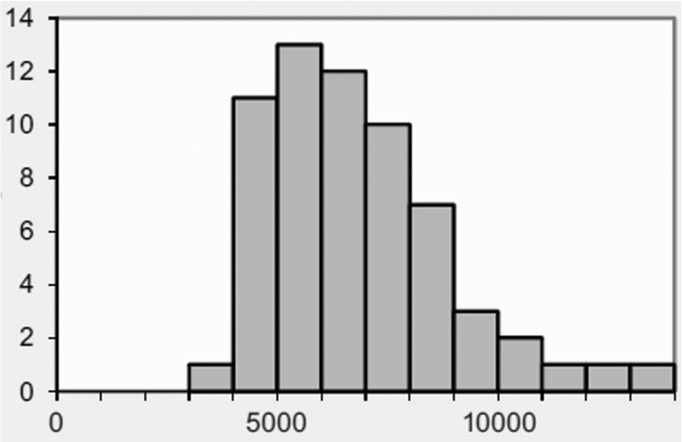


Figure 15: Statistical distribution of the strength of the knee muscle of sports students (from Mathelitsch & Thaller, 2012)

Many scientists tried to predict how soon a record would be broken, or what will be the ultimate limit a man or woman can achieve. Figure 16 shows the development of the world record in the 100 m dash. The blue squares represent the data till 2008, approximated by an unrealistic linear prediction (green line), and a more realistic prediction based on a logistic function (red curve). This curve levels off and leads to an ultimate record value of 9.5 s, indicated by the thinner dashed line. But world records are rare events and therefore a different kind of statistics (like for earth quakes) has to be used (Einmahl & Magnus, 2008). These models also give an ultimate limit, which is 9.28 s (thick dashed line).

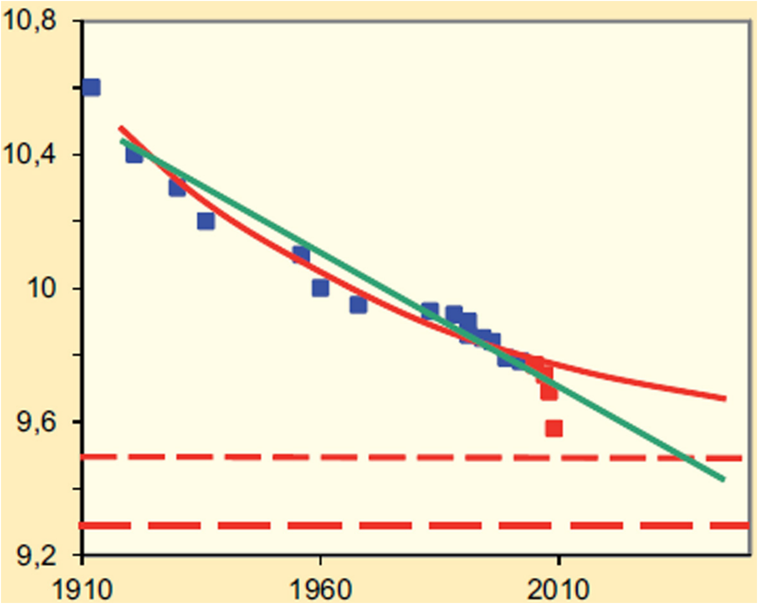


Figure 16: World record of 100 m dash (men) (from Mathelitsch & Thaller, 2012). Description in the text

Adding the last records, mainly by Usain Bolt (Hernandez Gomez, Marquina & Gomez, 2013), gives a strange picture, not seen in any prediction. But it was not only Usain Bolt, several other athletes showed similar improvement of their performance. In the meantime some of them were caught taking not-allowed drugs.

SHOT PUT

In shot-put we have the rare occasion that two techniques are applied at the same time. Some athletes use the O'Brien or glide technique (Figure 17), some the spin technique (Figure 18).

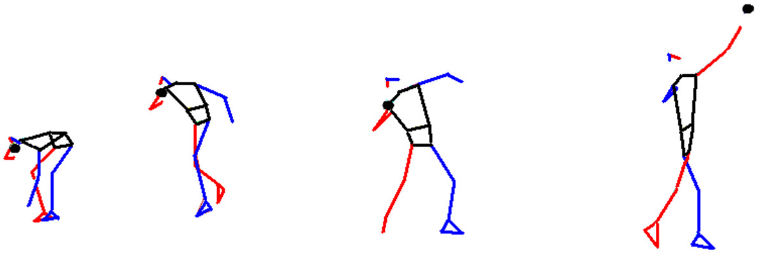


Figure 17: O'Brien or glide technique (from Mathelitsch & Thaller, 2008: p. 74)

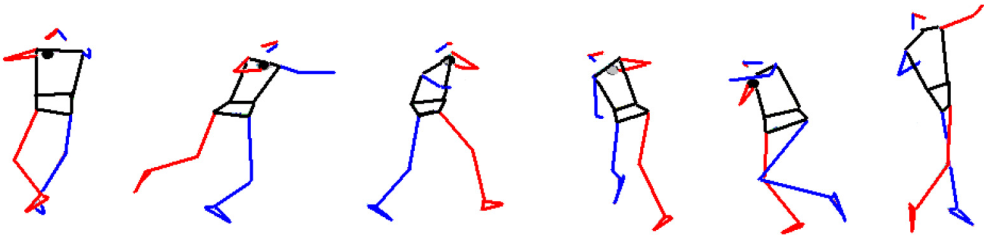


Figure 18: Spin technique (from Mathelitsch & Thaller, 2008: p. 74)

But now a new technique came up, here exemplified by the Viennese athlete V. Watzek: a cartwheel technique (Figure 19). Watzek obeys all rules that are not much: She has to stay within the circle, and the ball has to be on the body before the shot. She said that she had better results after a short time of training. Nevertheless, we will not see this technique, because it became forbidden. Official reason: it is not safe enough. V. Watzek claimed that this technique is safer since the movement goes always along the same line in the forward direction. The real reason is that the establishment struck back. Can you imagine that one of the male or female athletes who are the best in shot put could change to this technique?

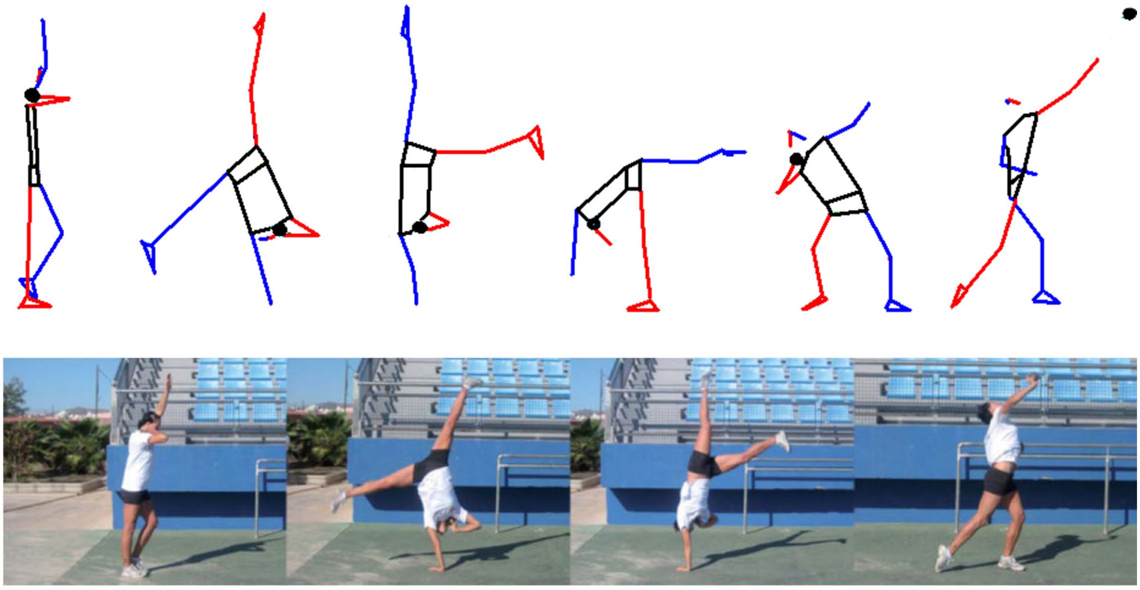


Figure 19: Cartwheel technique (from Mathelitsch & Thaller, 2008: p. 74, 75)

Conclusions

I hope I could demonstrate with some examples that the combination of sports and physics has a broad range of applications in school physics. With regard to the physics topic it concerns mainly applied mechanics. With regard to pedagogy many aspects can be addressed, experiments, video analysis, project work, interdisciplinary teaching, modeling. An implementation of examples as above has proven to interest also some of those students who were usually not fond of physics. Of course, this topic is not the magic bullet with which physics teaching will escape from the low ranking among the school subjects, but it could help to improve its image from being too abstract and difficult.

Acknowledgement

Most of the examples have been developed in close cooperation with Sigrid Thaller, Theodor Duenbostl and Theresia Oudin. I want to thank also Heimo Latal and Gerhard Rath for support in the preparation of this manuscript.

REFERENCES

Adair, R. K. (2002). *The physics of baseball.* New York: Harper Perennial.

American Journal of Physics. Available at http://ajp.dickinson.edu/

Armenti, A. (Ed.). (1992). *The physics of sports.* New York: American Inst. of Physics.

Ben-Naim, E., Vazquez, F. & Redner, S. (2007) What is the most competitive sport? *J. of the Korean Phys. Soc.*, 50, 124–126. Available at http://arxiv.org/abs/physics/0512143

van den Berg, E., Ellermeijer, A. L. & Slooten, O. (Eds.) (2008). *Modelling in physics and physics education.* Amsterdam: AMSTEL Inst. Univ. Amsterdam.

van Buuren, O., Uylings, P. & Ellermeijer, T. (2010). Towards a learning path for computer modelling. In D. Raine,Ch. Hurkett & L. Rogers (Eds.), *Physics community and cooperation.* Leicester: Univ. Leicester

Coach. Available at http://cma-science.nl/software/coach6/

Cross, R. (2011). *Physics of baseball and softball.* New York: Springer.

Denny, M. (2011). *Gliding for gold. The physics of winter sports.* Baltimore: The Johns Hopkins Univ. Press.

Dowie, J. (1981). Football's failing — the deadly draw. *New Scientist*, 91, 515–515.

Duenbostl, T., Mathelitsch, L. & Oudin, T. (1996). Experimente mit dem Tennisschlaeger. *Praxis der Naturwissenschaften-Physik*, 45(2), 2–9.

Einmahl, J. H. J. & Magnus, R. (2008). Records in athletics through extreme-value theory. *J. Am. Statist. Ass.*, 103, 1382–1382.

European Journal of Physics. Available at http://iopscience.iop.org/

Fontanella, J. J. (2006). *The physics of basketball.* Baltimore: Johns Hopkins Univ. Press.

Frohlich, C. (2011). Resource letter PS-2: Physics of sports. *Am J. Phys.*, 79(6), 565–574.

Gembris, D., Taylor, J. G. & Suter, D. (2002). Trends and random fluctuations in athletics. *Nature*, 417, 506–506.

Goff, J. E. (2010). *Gold medal physics: The science of sports.* Baltimore: Johns Hopkins Univ. Press.

Griffing, D. F. (2000). *The dynamics of sports: Why that's the way the ball bounces.* Dubuque: Kendall Hunt Pub. Comp.

Guttersrud, O. (2008). *Mathematical modelling in upper secondary education* [Dissertation thesis]. Oslo: Univ. Oslo ISSN, 1501–7710.

Haake, S. (2012). Material advantage. *Physics World*, July 2012, 26–26.

Häußler, P. & Hoffmann, L. (2000). An intervention study to enhance girl's interest, self-concept, and achievements in physics classes. *Journal of Research in Science Teaching*, 39, 870–888.

Häußler, P., Hoffmann, L., Langeheine, R., Rost, J. & Sievers, K. (1996). A typology of students' interest in physics and the distribution of gender and age within each type.

Int. J. Sci. Educ., 20(2), 223–238. Qualitative Unterschiede im Interesse an Physik und Konsequenzen für den Physikunterricht. *ZfDN*, 2(3), 57–69.

Haché, A. (2002). *Physics of hockey.* Baltimore: Johns Hopkins Univ. Press.

Heck, A. & Uylings, P. (2010). In a hurry to work with high-speed video at school. *The Physics Teacher*, 48, 176–181.

Hernandez Gomez, J. J., Marquina, V. & Gomez, R. W. (2013). On the performance of Usain Bolt in the 100 m sprint. *Eur. J. Phys.*, 34, 1227–1233.

Jorgensen, P. T. (1999). *The physics of golf.* New York: Springer.

Kaye, B. H. (1996). *Golf balls, boomerangs and asteroids.* Weinheim: VCH.

Kimball, J. (2010). *The physics of sailing.* Boca Raton: CRC Press.

Laws, K. (2002). *Physics and the art of dance.* New York: Oxford Univ. Press.

Lambourne, R. (2014) *E-Learning in Physical Science Through Sport: Learning objects and their dissemination.* In ICPE-EPEC 2013 Conference Proceedings. Prague: MATFYZPRESS. Available at http://www.icpe2013.org/uploads/ICPE-EPEC_2013_ConferenceProceedings.pdf

Lex, E. & Gunacker, E. (1998). Der Physik- und Chemieunterricht aus der Sicht des Schülers. *Plus lucis*, 98(1), 7–12.

Lind, D. & Sanders, S. P. (1996). *The physics of skiing: Skiing at the triple point.* New York: Springer.

Logger Pro. Available at http://www.vernier.com

Mathelitsch, L. & Thaller, S. (2006). Fußball mit wissenschaftlichem Maß. *Physik in unserer Zeit*, 37(3), 122–125.

Mathelitsch, L. & Thaller, S. (2008). *Sport und Physik.* Köln: Aulis Verlag.

Mathelitsch, L. & Thaller, S. (2012). Olympische Rekorde. *Physik in unserer Zeit*, 43(4), 186–189.

Measure Dynamics. Available from http://www.phywe.de

de Mestre, N. (1990). *The mathematics of projectiles in sport.* Cambridge: Cambridge Univ. Press.

Physics Education. Available at http://iopscience.iop.org/0031-9120/

The Physics Teacher. Available at http://scitation.aip.org/content/aapt/journal/tpt

Physics World, July 2012. Available at http://physicsworld.com/

Spathopoulos, V. (2013). *An introduction to the physics of sports.* CreateSpace Independent Pub.

Thaller, S. (2003). Hochsprung auf dem Mond. *Physik in unserer Zeit*, 34(9), 87–89.

Tracker. Available at http://www.opensourcephysics.org/webdocs/Tools.cfm?t=Tracker

Trumper, R. (2006). Factors affecting junior high school students' interest in physics. *Journal of Science Education and Technology*, 15(1), 47–58.

Turner, W. A. & Ellis, G. W. (1999). The Energetics of a Bouncing Ball. *The Physics Teacher*, 37, 496–496.

Viana. Available at http://viana.codeplex.com/

Wesson, J. (2002). *The science of soccer.* Oxon: Taylor & Francis.

Wiese, J. (2002). *Sports science.* New York: John Wiley.

Wilson, D. G. (2004). *Bicycling science.* Cambridge: MIT Univ. Press.

LEOPOLD MATHELITSCH
Inst. Physics, Univ. Graz, Austria

Scientia in educatione 8(Special Issue), 2017
p. 42–58
ISSN 1804-7106

Active Learning in the Heureka Project — Teachers in the Role of Students

Irena Dvořáková

Abstract

Our long-term Heureka project is based on the principle of active work in learning and teaching — both at school with students and in teacher training. Teachers in our seminars work the same way as students at schools — solving the same problems, doing the same experiments and sometimes even making the same mistakes. Our seminars provide long-term systematic training — the cycle of seminars for new participants takes ten weekends during the course of two years. That gives all participants the possibility and especially the time to change their approach to teaching physics.

The character of our seminars is rather informal: the seminars are free of charge and teachers join Heureka on a voluntary basis, gaining no formal advantages or benefits at their schools. The seminars take place during weekends, with teachers staying (and sleeping) in classrooms. In the autumn of 2012, we started already the 6th seminar cycle. Over the years, we have built a network of about 150 active teachers who have the possibility to meet at various advanced seminars and at "The Heureka Workshops" annual conference. The conference regularly attracts more than 100 participants and includes international guests.

We are convinced that our experience could be interesting and inspiring for other people working in physics education in different countries.

Key words: active learning, teachers training, The Heureka Project.

1 INTRODUCTION

Do you know any teachers training —

- where participants are really active?
- which is organized during weekends and lasts two years?
- which is voluntary and free of charge?
- where participants are accommodated in school, sleeping in their sleeping bags in the classrooms?
- in spite of these non luxury conditions teachers come again and are keen in participating this project?

Do you know such teachers training? If yes, you maybe know (part of) The Heureka Project.

The following text concerns this project, its principles and methods. Several concrete examples of methodological sequences, many tasks and comments from my school work are presented. You can find here a detailed description of three lessons (concerning measurement of time), one labwork (weighing using a piece of a paper) and two tests. This text gives also the results of a research, where the scientific reasoning of students that attended the Heureka programme was evaluated. The second part of the article describes the teachers training programme that we organize since 2002.

1.1 A FEW PERSONAL WORDS (THAT YOU CAN SKIP)

Before describing The Heureka Project I would like to say something about my work, because the whole project reflects my long time experience from my school work. I am a lector at the Department of Physics Education at the Faculty of Mathematics and Physics, Charles University in Prague. Our department focuses on the preparation of future physics teachers, but organizes also many activities for students from secondary schools and for physics teachers. We also do research in physics education, authors of several textbooks work in our department, etc.

I am also a teacher. I have a part time job at a lower secondary school in Prague. I teach physics to children of ages from 12 to 15 years. For me being a normal teacher is very important. I know how today's children look like, I know the problems in real schools. When speaking with my students at the faculty, I can describe to them some real situations at school, give them examples from my school work. Moreover, my school gives us a good base for the Heureka seminars.

1.2 FORMATION OF THE HEUREKA PROJECT

In the 90s, a group of about 5 people started finding ways to teach physics more actively and interestingly. For me it was very interesting to find, when working on my PhD. thesis many years later, that this empirical approach has many similar characteristics to modern pedagogical approaches, like constructivism and IBSE.

At the beginning we focused only on work with children in my school. Gradually other teachers became interested in our method, wanted to join and teach using this method, so we started to organize weekend seminars for them and the main aim of the project changed to the teacher training.

2 THE FIRST MAIN PART OF THE HEUREKA PROJECT — WORK WITH CHILDREN

The two following examples provide a good illustration of our approach.

2.1 EXAMPLE OF THE METHODOLOGICAL SEQUENCE — MEASUREMENT OF TIME

Children in the sixth class (about 13 years old) learn about measurement of the basic physical quantities (length, mass, temperature), and also time. We speak about different ancient clocks and then I tell children a story about Galileo and his investigation of pendulum. I ask children what properties the motion of pendulum could depend on. Children usually come up with many different properties:

- mass of the body
- shape of the body
- length of the string
- deflection at the beginning
- thickness of the string

Together we find that for an appropriate body, a thin string and small angles the motion of the pendulum depends only on its length. This investigation is a task for the next lesson.

For the next lesson I prepare a table for pupils' results. Children work in pairs. Their task is to measure the number of cycles per ten seconds for two different lengths of the pendulum. Each measurement is repeated twice. After measuring children fill in the table (Table 1).

Figure 1: Measuring in the classroom

Figure 2: Measuring in the classroom

When all groups finish their task, children write the two important columns — length and average number of cycles — in their exercise books. I give them a piece of millimetre graph paper and tell them that they have to draw a dot graph as homework. For most of the children this is the first graph ever they do in the school, so they need some hints. I show children how to start with two axes, discuss with them the scale on both axes, and how to find the point that corresponds to particular coordinates. I also tell them to draw only dots, not a curve. Children draw a graph at home. It is a hard task for them, but usually almost all of them are able to do it. At the beginning of the next lesson I check their work very quickly. Children correct their graph, if it is possible.

Table 1: Example of the results of measuring the number of cycles of the pendulum per ten seconds for different lengths (children's results, age about 13, April 2012)

Group	**Length (cm)**	**Number of cycles per 10 s**		**Average**
		1.	**2.**	
A	10	17	17	17
B	15	9	10	9.5
C	20	9	10	9.5
D	25	11	11	11
E	30	9	9	9
F	35	9	9	9
G	40	8	8	8
H	45	7.5	8	7.75
I	50	7.5	7.5	7.5
J	55	6	6	6
K	60	7	7	7
L	65	6	6	6
M	70	7	7	7
A	75	5.5	6	5.75
B	80	6	6	6
C	90	6	5.5	5.75
D	100	5.5	5.5	5.5
E	110	5	5	5
F	120	5	5	5
G	130	4	4	4
H	140	4.5	4.5	4.5
I	150	4	4	4
J	160	4	4	4
K	170	4	4	4
L	180	4	4	4
M	190	3.5	3.5	3.5

On the following figures you can see the expected result of the homework and the common wrong result, when a pupil did not listen to my hints and comments well.

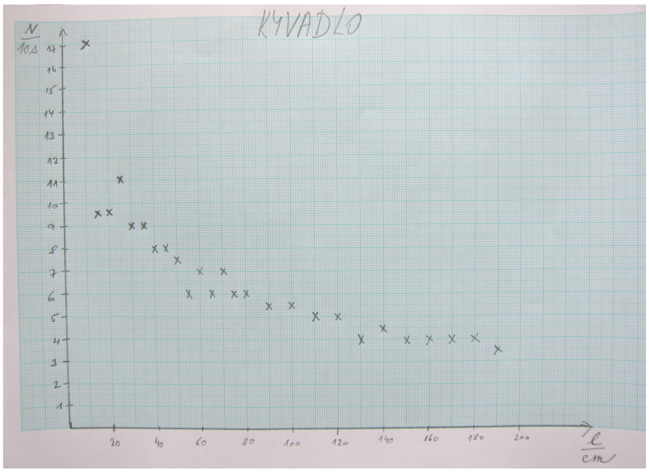


Figure 3: Number of cycles per 10 s versus length — Expected result

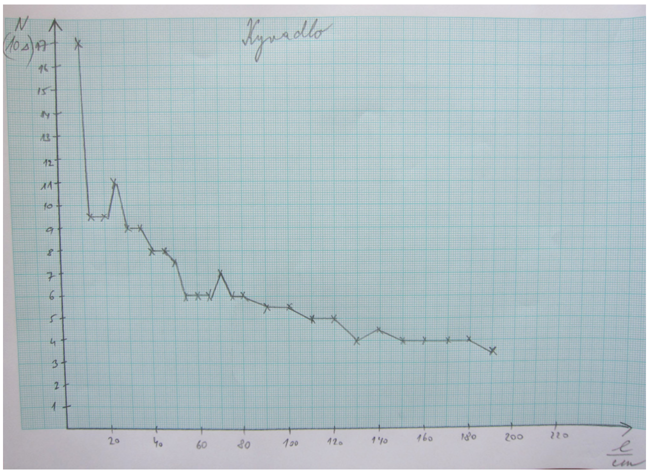


Figure 4: Example of a typical incorrect result

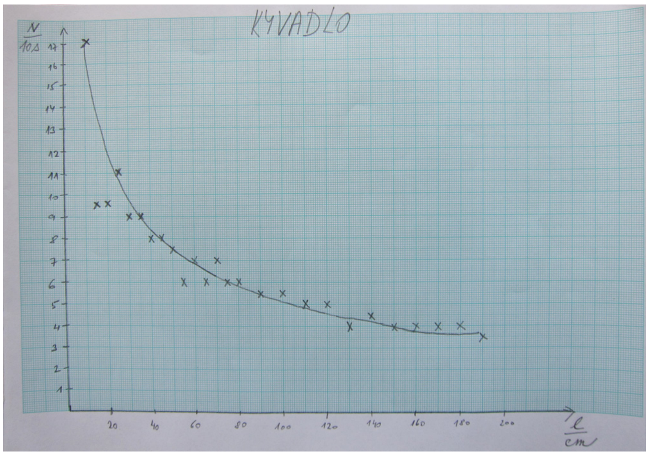


Figure 5: The curve showing how the number of cycles of the pendulum per ten seconds depends on the length (measured data)

After checking the homework I tell children — take a pencil and draw a curve free hand, i.e. the curve, which roughly passes through the dots. Children are first very surprised, but in the end they draw something like this (see Figure 5).

Then I show children the precise graph with calculated values and we compare both graphs. I don't tell children "the formula"; I only tell them that the graph is made using a mathematical expression.

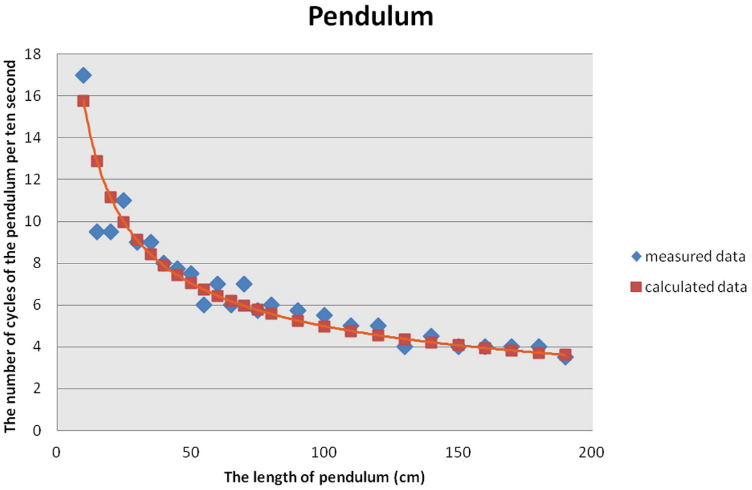


Figure 6: The graph shows both measured and calculated data

We discuss what the graph tells us. Children answer different questions like — You have a pendulum which is 32 cm long, could you find its number of cycles per 10 seconds? How long should a pendulum be which is ticking each second?

At the end of this lesson we speak about the function of a pendulum in mechanical clocks.

2.2 COMMENTS ON THE METHODOLOGICAL SEQUENCE MEASUREMENT OF TIME

When speaking about this approach, the first question teachers give me usually is "Why do you measure the number of cycles per ten second, instead measuring its period? It would be certainly easier for children and more precise." The answer is simple. Imagine how a period of pendulum depends on its length. In case we measure a period, the result will be a different curve (see Figure 7). In this case all children would use a ruler and draw a straight line. It would be hard to persuade them that this is not a straight line.

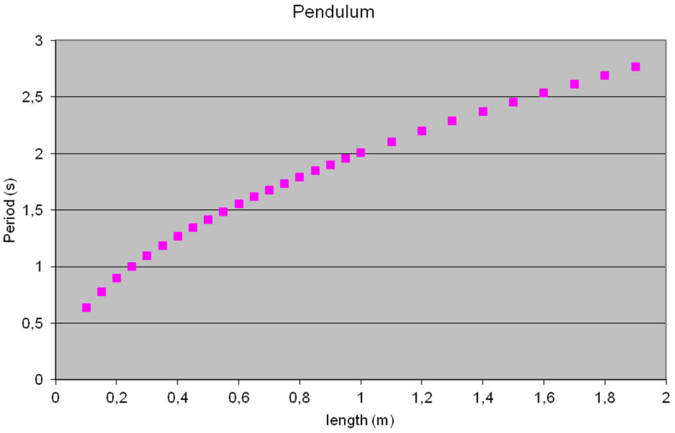


Figure 7: The period/length dependence graph

I must say I consider this sequence to be one of the most important topics in the 6th grade. In the first year of learning physics, children are able to work really like physicists — they formulate the hypothesis, verify it, collect real data, work with them, draw a non-linear graph, discuss this graph, read information from it, compare measured and calculated results, etc. Children will use all these skills (or competencies) during their entire physics studies. Moreover, I use another task concerning pendulum as a lab work in the ninth grade, so children can apply their findings in a different situation several years later. This is the reason I spent three lessons on such a seemingly trivial problem like the principle of a pendulum.

2.3 EXAMPLE OF A WRITTEN TEST

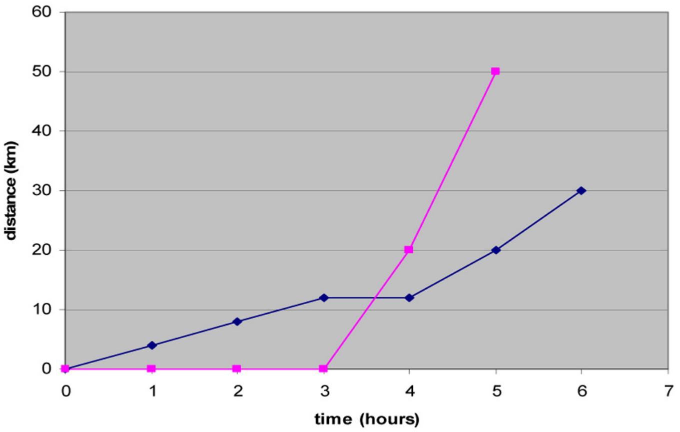
My second example is a test:

WRITTEN TEST IN THE 7TH GRADE — OCTOBER 2012

1. *A child is on a merry-go-round (carousel). What should the child do and how should the merry-go-round behave to accomplish the following situations:*
   - *a) the child is at rest with respect to the merry-go-round and in motion with respect to the Earth,*
   - *b) the child is in motion with respect to the merry-go-round, at rest with respect to the Earth,*
   - *c) the child is in motion with respect to the merry-go-round and to the Earth too*
   - *d) the child is at rest with respect to the merry-go-round and with respect to the Earth too.*

2. *A motorboat has a speed of 20 metres per second and it takes it 40 min to travel the distance between two ports. How far are the ports? How long does this journey take for a slower boat, which goes at a speed of 10 km per hour?*
3. *The bus went 0.5 hours at a speed of 50 km per hour, then the next 20 km it went at 40 km per hour, then it stood still for half an hour. Then it covered the remaining 100 km at a speed of 50 km per hour. Calculate how many kilometres it covered in total and how long it took (including the rest). Calculate the average speed of this motion. Draw a graph showing the distance-time dependence.*

4. *You can see a photo of a guidepost on which distances are given in hours, not in kilometres. Explain in which regions it is used and the reason for it.*
5. *Design some processes, the speed of which makes sense to measure in: a) cm per hour, b) litre per minute, c) kg per year, d) mm per year.*
6. *Write a story to the graph:*



2.4 Comments on the test

As you can see the first three tasks are common tasks you can find in all collections of problems. The tasks number four and five require children to apply their knowledge in a new situation; they did not solve similar tasks before the test.

I would like to emphasize the last task. Children have to think about what bodies probably move (according to their velocity), how their movement looks like, and, moreover, to create a simple story. In my experience this type of tasks is interesting for children for example as a voluntary homework, too. Children like it very much and their stories are very pretty.

Grading this type of exam is not easy for teacher. It is necessary to understand students' ideas, which are sometimes a bit complicated. But my goal is to develop students' thinking, so my tests must require thinking, too.

One important comment: Sometimes teachers who do not teach according to Heureka want to use my tasks. I usually tell them “Be careful. It is not fair to give those tasks to your students in case you use a traditional teaching approach. You cannot require students' thinking in a test, if you do not require their thinking in lessons.”

2.5 THE BASIC PRINCIPLES OF THE HEUREKA APPROACH

As I said before, the basic principles of The Heureka Project are in agreement with many modern trends in physics education worldwide, in spite of the fact that the authors arrived at these principles independently. The authors had no connection with pedagogical research at that time, because until the early 1990's it was very difficult in the Czech Republic to obtain foreign pedagogical literature.

The most important of these principles include:

- A high rate of student/teacher interaction.
- An inquiry-based approach to teaching.
- Nature is the final authority, not the words of the teacher.
- Mistakes are normal and an important part of the learning process.
- The starting point of teaching and learning is a question and observation.
- The specific physical terms are defined at the end, after observation of experiments and description all important properties.
- We start from things that children know from everyday life.
- Students are not merely passive "objects of education," but are led to think about problems, formulate hypotheses and use experiments to verify them.

I hope at least some of these basic principles are visible in my previous examples.

2.6 IS THERE SOME REAL IMPACT OF THE HEUREKA APPROACH ON THE THINKING ABILITIES OF STUDENTS?

This is a question I was already interested in, but I had no ways how to measure it, until I learned about a Lawson's test of scientific reasoning several years ago. This test is based on Piaget's research; it is able to measure concrete- and formal-operation reasoning. It consists of 12 pairs of items. An item is scored correct only if the correct answer is checked **and** also an adequate explanation is given. The maximum number of points is 24. You can find the ideas of the test, its methods and results in articles (Lawson, 1978a, 1978b, 1984, 1985; Renner, 1993; Dewey, 2011), it is not the topic of this article. For me it was important that it is possible to use the test for determining the developmental levels of my students. I found that this is a method which allows me to measure students' abilities.

I decided to test my students at the end of attendance at our school. You can see the results of my students since 2010 to 2013 in Table 2. The next idea was to compare the results of students who learned according to The Heureka Project with students who are not taught according to Heureka. I asked my colleagues who use the Heureka approach and several teachers who do not use this approach to test their students. The age of my students and other students in "the Heureka group" was 15–16 years, the age of students in the control group was 15–18 years. Table 3 shows the total results, Table 4 shows the distribution of students on developmental-reasoning levels described in Piaget's research. The same results are also shown in graphs (see Figure 8 and Figure 9). Though this does not represent any larger formal pedagogical research yet, I think it may be interesting to see even the partial results.

The difference between means is highly statistically significant. Further pedagogical research in this area should be done to get general conclusions, but these results seem to clearly indicate that the Heureka approach has a positive impact on the thinking abilities of students.

Table 2: Results of the scientific reasoning test — Lower elementary school, Prague 6 (my classes)

Year	Number of students	Average number of points
2010	23	14.7
2011	21	12.5
2012	20	13.1
2013	29	14.8

Table 3: Complete results of the scientific reasoning test (all groups)

Group	Number of students	Average number of points	Average result (in %)
All my students	93	13.8	57.4 %
All classes learned according to the Heureka Project	374	12.7	53.1 %
Control group — students who did not learn according to the Heureka	521	8.9	37.1%

Table 4: Distribution of students on developmental-reasoning levels (Piaget)

Level		Heureka group		Control group	
		Number	in percents	Number	in percents
1	**Concrete operational level (0–8 points):**	87	23.3%	278	53.4%
2	**Transitional level (9–16 pts):**	196	52.4%	200	38.4%
3	**Formal operational level (17–24 pts):**	91	24.3%	43	8.3%

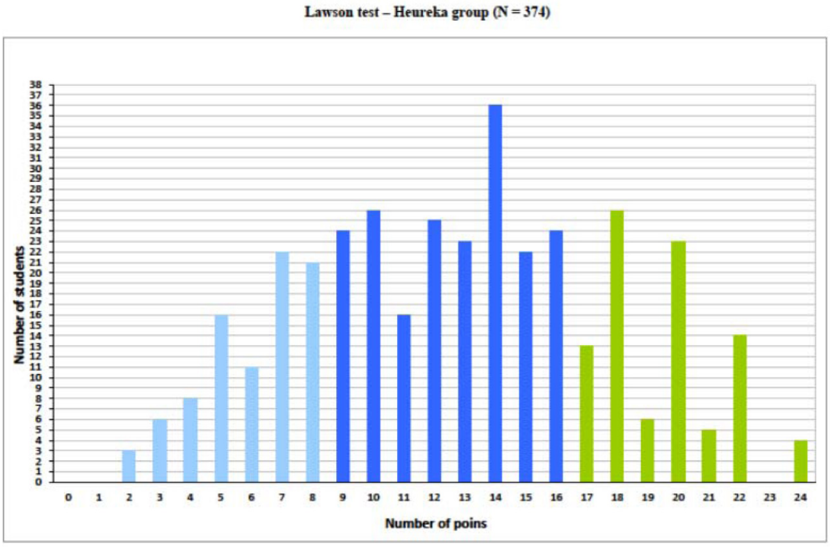


Figure 8: Results of the scientific reasoning test — The Heureka group

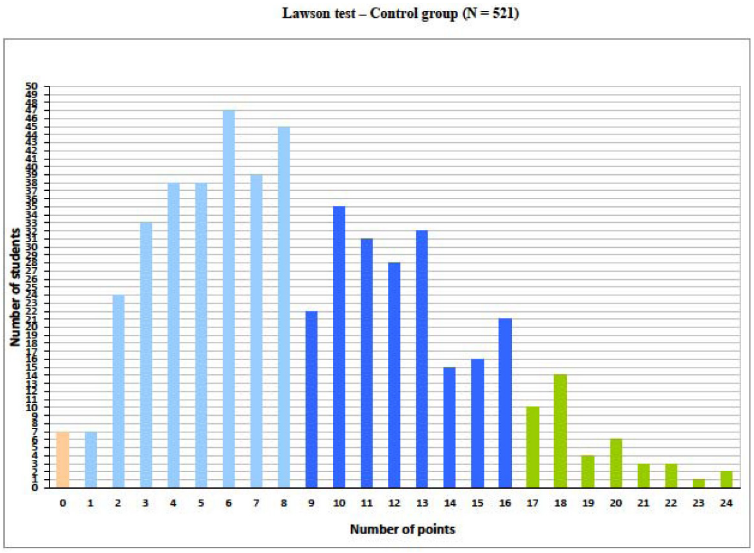


Figure 9: Results of the scientific reasoning test — The control group

3 THE SECOND MAIN PART OF THE HEUREKA PROJECT — WORK WITH TEACHERS AND FUTURE TEACHERS

The basic principles mentioned above we use not only in the work with students, but also in the work with teachers. Nowadays we consider teacher training to be the most important part of The Heureka Project.

We organize several types of seminars and prepare an annual conference. All seminars are completely voluntary; participants have no formal advantages or benefits at their schools. The only benefits are the teaching methods, plans of lectures, problems and tasks, etc., which they obtain during seminars. All are published on the internal web pages of the project. Examples of methodological materials were published also in journals and at web pages. All seminars are also free of charge. Our seminars take place in schools, so they are very informal. Participants sleep in their sleeping-bags in classrooms and they have to bring food with them (see Figure 10 and Figure 11). In spite of those conditions, we have more than 150 active participants, some of them even from Slovakia.

Figure 10: "The dining room"

Figure 11: "The sleeping room"

3.1 SEMINARS FOR NEW PARTICIPANTS

These seminars are intended for teachers who want to learn Heureka's teaching methods. Seminars are organized during weekends not to interfere with teachers' school work. The whole course consists of 10 weekend seminars during a two year period. Participants work at these seminars very similarly to students at school. They do experiments, solve problems, sometimes write tests, do voluntary homework, etc. (see Figure 12). Seminars are focused on:

- new approaches to teaching
- basic physics knowledge and its application
- personal development of participants
- games and other activities suitable for work with children

Besides this they discuss teaching methods they have seen and talk about pedagogical problems in their schools, too.

Figure 12: Teachers work at seminars similarly to students

To know more about the participants' opinions, we ask them to write a structured feedback at the end of every seminar. But maybe the best feedback is the fact that teachers continue to come to seminars and spend ten weekends with us. Based on the teachers' own feedback, we can say that the professional competencies of teachers are increasing during the seminars.

Apart from the structured feedback described above, we also ask teachers what they appreciate about these seminars. Twenty three teachers from the fourth course for new participants in 2008/2010 were asked what the attendance of these seminars had brought to them. During the last seminar of the course they completed a small questionnaire with nine open questions. (i.e.: *“What changes have you found in your teaching during the last two years?”, What have you learned in these seminars?”*, etc.). The essential part of their answers is summarized in Table 5.

Table 5: Benefits of the teachers' attendance in the Heureka seminars

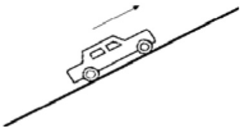
Benefits of the attendance in seminars	**Number of respondents**
Inspiration, getting manuals for teaching	23
Meeting with the same type of people, new friends	19
I learned how to activate more students at school	16
I am more self-confident, I am not afraid to make mistakes	12
Improvement of knowledge of physics	9
It "gives me energy"	7

Teachers called this course "the teachers' kindergarten", because we really start our work from the first lesson in the sixth grade, where children start learning physics, too. It could be unusual to teach physics from scratch teachers who graduated in universities. But in our experience many participants of our seminars are able to calculate difficult tasks but have difficulties with understanding some basic concepts.

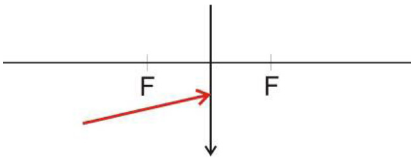
We check these basic ideas using several conceptual problems in the test at the beginning of the first seminar. I recommend you to try to solve the four problems and write your solution before you will read the text further. Maybe you will better understand why our participants start to learn physics from scratch.

TEST FOR NEW PARTICIPANTS (PART OF THE TEST)

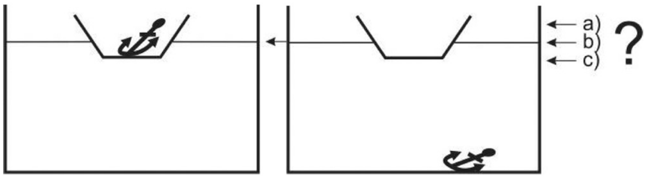
1. *A car of mass 2 500 kg goes up a hill (with a gradient 10 %) for two minutes at speed 50 km/h. A figure shows its position after one minute. Draw the net force (i.e. a sum of all forces) acting on the car.*



2. *A figure shows a convex lens (a magnifying glass), positions of its focal points and a general ray approaching the lens. Draw the ray after it passes through the lens. (Find the precise solution, not any approximation).*

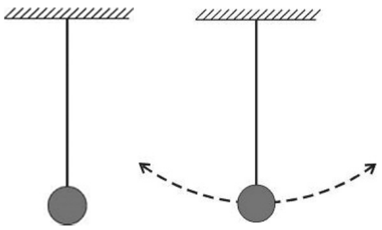


3. *In a little pool, there is a small boat with an anchor inside the boat. We mark the level of water on the wall of the pool. How does this level change if we drop the anchor to the bottom of the pool?*
Select the right variant and explain your reasoning:



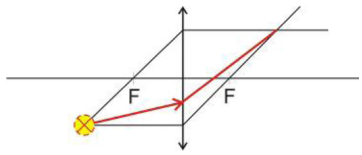
   a) *The level of water rises.*
   b) *The level stays the same.*
   c) *The level of water falls.*

4. *The first figure shows a pendulum hanging at rest. In the second figure, there is a moving pendulum shown just at the moment when it goes through the lowest point of its trajectory. Draw the net forces acting on the pendulum in both cases.*



The solution of the test

1. *The car performs rectilinear motion with a constant velocity, so $F = 0$ (the 1st Newton law).*
2. *Choose a source of the ray, find the image of the source, the general ray goes to this image after passing through the lens (as all other rays passing through the lens).*



3. *The experiment shows the result. As you can see on photos, the final level of water is lower than the initial.*

4. *First situation — the pendulum is at rest, so the net force $F = 0$ (The 1st Newton law). Second situation — the pendulum moves along the circle, the net force is centripetal.*

We can therefore conclude — seminars for new participants allow teachers to:

- re-learn physics from the beginning
- get their own experience with active learning
- obtain experience with their own misconceptions
- achieve higher tolerance to students' mistakes during a teaching-learning process
- understand the necessity of a safe atmosphere in the classroom

3.2 Other seminars — for students and for more experienced teachers

There are also seminars for students of our faculty (future teachers of mathematics and physics), who are interested in The Heureka Project. These seminars are organized very similarly to teachers' seminars for new participants, only not during weekends, but as a standard voluntary seminar (consecutive seminars in 4 terms, two hours per week). Usually more than 80 % students from each year attend this seminar.

We also organize seminars for experienced teacher who already finished "the teachers' kindergarten". Those seminars have usually one specific topic — e.g. Physics in Biology, History of Physics, Modern technology in the school, etc.

THE HEUREKA WORKSHOPS

"The Heureka Workshops" is an annual conference prepared both for physics teachers and for students — future physics teachers, who attend any of seminars of The Heureka Project, and for guests, too. There were about 130 participants (some of them with their children) in 2013.

To allow teachers to attend the conference without problems in their schools, we organize it during the weekend (usually the first weekend in October).

The characteristic attribute of this conference is its form. The whole conference is organized as a set of workshops (19 workshops were prepared in 2013; two of them were led in English by guests from abroad). There are no invited speakers, no lectures, and no formal meetings. Each workshop takes 90 minutes and repeats typically four times. The workshops are prepared and led by teachers from schools or from a university. The active work of participants is an essential requirement for each workshop. There are no other limitations. The topic could be a set of experiments, building some simple instrument, measurement of some properties of materials, games useful for physics teaching, etc. We built also *Dancing bugs* or *Bridges from newspaper* (Lipertova, 2011; Piskac, 2008) in the past. Every year we are surprised how many interesting ideas the teachers have.

As mentioned above, the conference is very informal. It takes place in the high school of a small town Nachod in East Bohemia, where one of the active teachers from The Heureka Project works. Participants sleep in classrooms in their sleeping bags, bring their own food, there is no welcome drink or conference dinner. Maybe this informal character supports the friendly atmosphere of this meeting. Teachers can talk to each other while eating or before sleeping, there are no formal barriers there.

We are pleased that guests from abroad come to Nachod every year in spite of the fact that the conference is conducted in the Czech language and living conditions are far from luxurious. According to our experience, there was never any problem with mutual understanding — either the head of the workshop is able to speak both Czech and English or somebody translates for a foreigner. Some of our guests described their experience and impressions from the conference in reports published in international journals (Swinbank, 2005; Planinsic, 2006; Milbrandt, 2010). We would like to invite readers who are interested to participate in next years' conferences which will be organized at the beginning of October each year.

4 BONUS — WEIGHING USING A PIECE OF PAPER

Finally I would like to present an excellent idea of Zdenek Polak, the local organizer of the conference The Heureka Workshops.

This is an example of the simplest scales, which are nevertheless able to weight with a considerable precision. This is a very nice application of the lever, that's why I usually use measuring with these scales as a labwork afterwards we learn about simple machines (a lever, a pulley, etc.). Children measure the mass of all Czech coins; they work individually, not in pairs. They fill in their results to the table on the blackboard (similarly as in the example concerning the pendulum mentioned above) and finally compare them with the official bank values.

You can determine the mass of a coin, a ring, etc. using only:

- a piece of paper
- a pin
- a ruler (for measuring the length)

HOW TO GET A WEIGHT?

On the package of printing paper it says that the square density of paper is 80 $\mathrm{g/m^2}$. It means, that 1 $\mathrm{m^2}$ of paper (format A0) has a mass of 80 g. One page of paper (format A4) is $1/16\ \mathrm{m^2}$, so its mass is 5 g.

HOW TO GET SCALES?

You can fold your piece of paper several times (see Figure 13) to make scales.

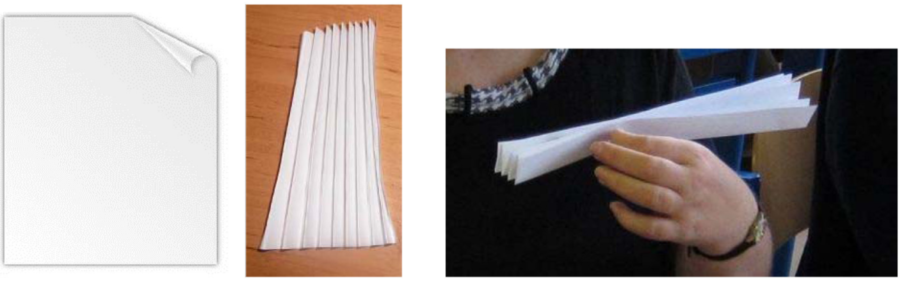


Figure 13: Making scales

HOW TO MEASURE?

Find the centre of mass of the paper (point T). Choose the point for an axis of rotation
(A, so A is off-centre), the distance $a = |TA|$ should be about 4–5 cm. Use a pin as an axis of rotation. Now you have a scales, where on one side (in the point T) is a mass of 5 g (mass of the paper), on the other side you will put a measured body. Put a coin (a ring, . . .) on scales, find its right place for equilibrium (see Figure 14). Measure the distance (b) between the centre of measured body and the axis.

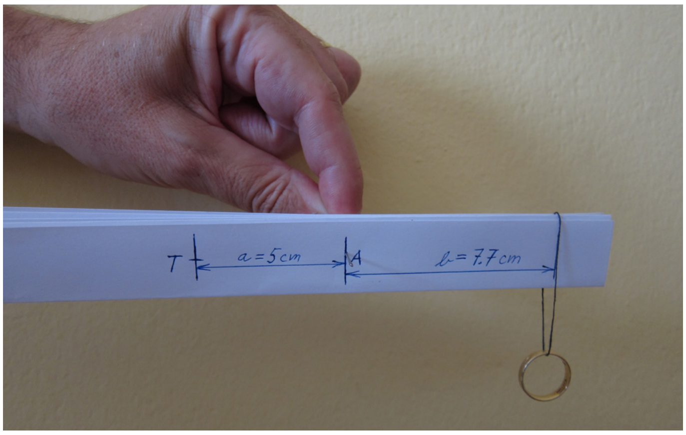


Figure 14: Equilibrium on scales

How to calculate?

Calculate the equation of a lever:

$$F_1 \cdot a = F_2 \cdot b$$

For my ring this worked out as follows:

$$\begin{aligned}
&\text{mass of the paper} = 5\ \text{g}\\
&\text{mass of the ring} = x\\
&a = 5\ \text{cm}\\
&b = 7.7\ \text{cm}\\
&5\ \text{g} \cdot 5\ \text{cm} = x \cdot 7.7\ \text{cm}\\
&x = 25/7.7\ \text{g} = 3.2\ \text{g}
\end{aligned}$$

Using precision digital scales I found that the mass of my ring is 3.295 g.

As you can see, this simple instrument is able to weight surprisingly precisely.

5 Conclusion

I described the history and the current state of The Heureka Project. Thanks to the recently acquired support of the Depositum Bonum Foundation, Heureka now has the opportunity to start a new stage of its development. The Foundation is seeking to improve science education in Czech elementary schools. One useful way of promoting this goal is to support physics teachers. With the new school year (2013/2014) the Foundation and Heureka opened fifteen regional centres for physics teachers. The centres are led by teachers who have their own experience with Heureka and who are able to organize monthly meetings for other physics teachers in their regions. The main goal of the meetings is to support the professional development of teachers by giving them an opportunity to share their experience, learn about some new experiments and teaching approaches and borrow modern teaching tools. Built jointly by the Depositum Bonum Foundation and Heureka, the centres are firmly rooted in Heureka's principles which I have outlined above and which have brought tangible improvements into Czech classrooms.

After two decades of existence and growth, The Heureka Project is starting a new stage in its long-term evolution.

References

Dewey, I. & Dykstra, Jr. (2011). Physics Teaching and the Development of Reasoning. *sciED*, 2(2). Available at
http://www.scied.cz/Default.aspx?ClanekID=345&PorZobr=1&PolozkaID=132

Lawson, A. E. (1978a). The development and validation of a classroom test of formal reasoning. *Journal of Research in Science Teaching*, 15(1), 11–24.

Lawson, A. E., Karplus, R., & Adi, H. (1978b). The development of propositional logic and formal operational schemata during adolescence. *Journal of Research in Science Teaching*, 15(6), 465–478.

Lawson, A. E. & Bealer, J. M. (1984). Cultural diversity and differences in formal reasoning ability. *Journal of Research in Science Teaching*, 21(7), 735–743.

Lawson, A. E. (1985). A review of research on formal reasoning and science teaching. *Journal of Research in Science Teaching*, 22(7), 569–618.

Lipertova, K. (2011). Dancing bugs. Available at
http://www.youtube.com/watch?v=rf-QP0gfKiE and
http://www.youtube.com/watch?v=AhTIQEgQeSE

Milbrandt, R. (2010). Innovative physics teaching conferences in the Czech Republic. *The Physic Teacher*, 48, p. 395–396.

Piskac, V. (2008). Bridges from newspaper. Available at
http://www.youtube.com/watch?v=27cbeFSi7-M and
http://www.youtube.com/watch?v=rVCSObipAOM

Planinsic, G. (2006). Teachers share experiment know-how. *Physics Education* 41, p. 7–8.

Renner, J. W., Lawson, A. E. (1973). Promoting Intellectual Development through Science Teaching. *Physics Teacher*, 273–276.

Svinbank, E. (2005). Reporting from a mattress in Nachod… *Physics Education* 40, p. 5.

Irena Dvořáková
Faculty of Mathematics and Physics, Charles University, Prague,
and Junior Secondary School Cerveny vrch, Prague, Czech Republic

sciED

Scientia in educatione 8(Special Issue), 2017
p. 59–78
ISSN 1804-7106

Physware: A Collaborative Initiative for Strengthening Physics Education and Promoting Active Learning in the Developing World

Pratibha Jolly

Abstract

Project *Physware* emanates from globally shared concerns on the lack of high-quality education in physics with detrimental consequences on scientific research and socio-economic progress. A significant milestone in international cooperation, *Physware* aims to provide a sustainable collaborative model for capacity building of physics educators through a series of *Educate the Educator* workshops for those in the developing countries. The workshops are carefully designed to promote activity based pedagogic methods proven to be effective through rigorous educational research. They propagate curriculum and resource materials that are easily adapted to the needs of any region. While the emphasis is on using low-cost equipment and appropriate technologies that are locally accessible, participants are also introduced to ways of integrating emerging computer-based technologies for physics teaching, contemporary research, and applications of relevance to the work place. They explore ways of teaching fundamental new physics within the context of contemporary pedagogy that is both, hands-on and minds-on. After the success of a pilot workshop held at Trieste in 2009, the *Physware* series was launched in 2012 from the University of Delhi. Both workshops brought together a vibrant and eclectic group of participants who contributed actively to creation of innovative resource materials. It is hoped that many participants will emerge as regional leaders. Feedback shows that going beyond the constraints of its workshop format, *Physware* has the potential to emerge as a professionally networked community of practice.

Key words: educate the educator, physics education research, active learning, low cost equipment, community of learning and practice.

INTRODUCTION

The turn of the century has ushered a greater sensitivity to the common denominator of problems faced by humankind and reinforced the need for finding collaborative solutions. It is widely recognized that in an interconnected world, science and technology will continue to be the key instrument that will decide the pace of further social and economic progress across the globe. The spotlight is now focused on the so-called emerging and developing countries — their potential, changing aspirations and capacity to contribute to global economies. Education and health for all, inclusive growth, greater sensitivity to environmental challenges and issues of sustainability underpin global development agenda and discourse. The national goals of developing countries, in particular, now lay greater stress on access, equity and excellence in education. Recognizing the importance of building a technological backbone employing indigenous research and development programs, the world educational community understands the increasing need to adopt the best pedagogical praxis to meet global benchmarks in the long run (Science, 2013).

Paradoxically, despite the major strides in science, the quality of the human resources in science and technology continues to be an area of grave concern not just in the developing countries but across the world. International surveys and assessment of performance tests such as TIMMS (Trends in International Mathematics and Science Study), ROSE (The Relevance of Science Education) and PISA (Programme for Student Assessment) flag serious issue about the state of science education. Growing apprehensions also include the dwindling interest in science amongst young students, the lack of quality in science education in general, the flight of talent from basic sciences and the evident disconnect between formal education and the needs of the workplace and national goals.

Active Learning: *Physware* emanates from and builds on the grave concern that, across the world, the predominant mode of teaching continues to be textbook based lectures. Laboratories are sometimes completely missing or not used appropriately as a part of the learning process in both developed and developing countries. Very few institutions, including those in developed countries, provide innovative learning techniques which are integrated throughout the students' learning of physics and which can help students visualize the physics they are learning and enhance their qualitative and quantitative understanding. Even where laboratory work and/or hands-on activities are an integral part of the curriculum, they often follow a cookbook approach that fails to impart procedural and conceptual knowledge about the activity, which then becomes hands-on without engaging the students minds.

Over the last few decades, systematic research in physics education has helped define a new agenda for teaching-learning environments the world over. Seminal research in physics education and cognitive science has conclusively established that students learn best when they are actively engaged in construction of their own knowledge. Active learning strategies entail engaging students in a carefully guided process of scientific enquiry that helps them to construct their knowledge of physics concepts by direct observation of the physical world.

Research on students' conceptual understanding shows that students bring to the formal classroom spontaneous reasoning based on naive theories about the world. These beliefs and ways of interpreting physical phenomena are significantly different from those they are expected to learn. To engender conceptual change, it is necessary to explicitly confront the students with situations that help them perceive the inconsistency or contradiction between their naive theories and the evidence generated by the phenomena. The resulting disequilibrium can provide the crucial intrinsic motivation for active learning. Guided enquiry methods make use of a learning cycle that includes predictions, small group discussions, observations and comparison of observed results with predictions. The goal is to make students aware of the differences between the beliefs that they bring into the introductory physics classroom, and the actual physical laws that govern the physical world. These learning strategies are known to measurably improve conceptual understanding and simultaneously aid development of good physical reasoning skills. Consequently, the current thrust is to develop active learning environments, instructional material and teaching strategies which are both, hands-on and minds-on (McDermott, 1999; Laws, 1997).

Rubric for Change: Developing and implementing active learning environments is no easy task. There are many reasons that we still have stagnant and traditional curricula. Active learning requires resource material tuned to the local framework. It needs basic equipment that is easy to procure — available off the shelf and affordable; easy to operate — with appropriate level of sophistication; easy to maintain — with available local technical support; robust — of good educational quality. Some of the equipment should be sufficiently modern — reflecting the state-of-art in education as developing communities also aspire for the best.

There is no clear rubric for change. The overwhelming question for any group attempting educational reform is where to make a beginning. Deep-rooted change affords no shortcuts. It is well recognized that import of curriculum packages, resource materials, experimental kits and equipment, however proficient, cannot fill the lacunae in individual programs. The "not invented here" syndrome can often lead to the collapse of an otherwise excellent idea transported from elsewhere. Thus, it is imperative for each group to continually look into the methodology and content of its programs and develop its own materials and mechanisms taking into account the special constraints in implementation. In education, the wheel has to be continually reinvented. Individual adaptations are necessary and unavoidable — in fact, it is the process of development itself that is of prime importance (Jolly, 2002).

Teacher Education: The role of the instructor when active learning materials are introduced into the classroom is of critical importance. This transition requires teachers to accept evidence that most introductory students do not learn effectively from logical explanations by instructors. Teachers must believe in the effectiveness of active learning materials. The ease of this transition is dependent not only on a willingness to give up the role of authority, but also on a number of cultural factors that differ from country to country. This is the ultimate challenge in introducing active learning teaching strategies in different parts of the developing world, and is a vital reason for designing activities that use low-cost equipment.

Large scale curriculum reform rests on creating several opportunities for professional growth for teachers. Onetime participation in a programme, however well conceived, is merely a positive spike that enhances motivation and professional competence for a short duration. The moot question is how transformative this trigger is and how deep rooted the change it brings about. Once back in the environment of their own country, institution and context, will the participants be able to bring innovation into classroom practice and leverage the enhanced pedagogical content knowledge. Diffusion and assimilation of innovation brings its own challenges. Large scale adoption and adaption of any new idea entails institutional commitment to systemic change, multi-dimensional support and most importantly, a critical mass of those who can affect the change, in letter and in spirit. Then the foremost requirement for transforming educational ecosystems is empowering and educating the educator and changing the understanding they have of the process of teaching-learning (Jolly, 2001).

BACKGROUND

Physware, conceptualized as a series of *Educate the Educator* workshops, is an initiative launched to enhance the quality of physics education at the undergraduate level, especially in the developing world. It is a direct outcome of recommendations from the physics education task force of the *World Conference on Physics and Sustainable Development* (WCPSD) from 30 October to 2 November 2005, at Durban, South Africa.

WORLD CONFERENCE ON PHYSICS AND SUSTAINABLE DEVELOPMENT (WCPSD)

Organized as part of the International Year of Physics (IYP) celebrations, WCPSD was co-sponsored by the Abdus Salam International Centre for Theoretical Physics (ICTP) at Trieste, Italy, the International Union of Pure and Applied Physics (IUPAP), UNESCO and the South African Institute of Physics (SAIP). WCPSD was different as it was visualized as the starting point of a long term world-wide initiative. The organizers identified that if physics is to impact sustainable development, there is need to understand and suggest action plans for the coming years in four critical areas, namely, Physics Education, Physics and Economic Development, Energy and Environment, and Physics and Health. The author Pratibha Jolly as Chair of IUPAP Commission 14 — the International Commission on Physics Education (ICPE) — and Priscilla Laws (Dickinson College, USA) were invited to co-chair the physics education segment. The Secretary of ICPE, Dean Zollman (Kansas State University, USA) joined the efforts as a key member of the Planning Committee that also included Minella Alarcon, Program Officer in charge of Basic Sciences at UNESCO and Associate Member of ICPE.

Physics Education Goals: One of the major concerns of WCPSD was to involve those in developing countries and help strengthen physics education in culturally relevant ways, determined and sustained by local initiatives. The Planning Group identified through its own network potential participants, especially from the developing countries. This stakeholder group joined an electronic forum to exchange views on the specific issues to address, themes for invited talks and breakout discussion for action planning. Vibrant discussions led to identification of guidelines for action planning. It was decided to limit focus to the improvement of physics education at the secondary and the university level, especially for future physics teachers in secondary schools. Further, it was decided to set up working groups at the conference to identify the common denominator of problems and suggest how best to promote basic physics teaching that is enhanced by the use of locally developed examples, assignments and projects that are familiar to teachers and their students.

WCPSD Action Plans: The WCPSD concluded with the formulation of specific action plans:

1. To give educators and students in developing countries access to high quality physics education resources by establishing a website and Physics Education Resource Centres in Africa, Asia and Latin America.
2. To develop supplemental instructional materials for secondary physics courses that help students understand how the mastery of physics concepts can enable them to contribute to sustainable development in their own countries.
3. To develop model workshops for teacher-trainers in Asia, Latin America and Africa that exemplify how active learning methods can be adapted to help meet the needs of students in developing countries.
4. To establish a structured multi-disciplinary mobile science community that provides support to mobile science practitioners, enabled by a website at http://www.mobilescience.info hosted by the Institute of Physics (UK).

The action plans were endorsed by all sponsors. IUPAP, in particular, reported the action plans at the meeting of its Council Chairs and Executive Council held at Institute of Physics, London in February 2006. The WCPSD Planning Group through ICPE was given the mandate of development of model workshops and resource materials for physics teachers and teacher trainers that exemplify how active learning methods can be adapted to meet the needs of students in developing countries and further, mechanisms for electronic sharing of high quality physics education resources by establishing a website. In view of its ongoing work, Institute of Physics UK, was given charge of implementing the last recommendation on Mobile Science (Jolly, 2006).

IUPAP RESOLUTION ON ACTIVE LEARNING AND HANDS-ON EDUCATION

In furtherance of its commitment to the WCPSD action plans, IUPAP adopted a resolution on importance of active learning, hands on education and laboratory work at the 26th General Assembly held in Tsukuba, Japan, in October 2008 (IUPAP website). The resolution urges that National Governments, Physical Societies, Funding agencies, Physicists, and Physics educators in all countries

- support best practice of physics education and physics education research at all levels by encouraging teaching methods, including laboratory work, that actively engage the hands and minds of learners.
- make available funds for establishment of well equipped laboratories and designing appropriate curricula that lay particular emphasis on teaching the skills of the experimenter.
- support indigenous development of low-cost instruments, physics apparatus and equipment, and — when finances allow it — computer-based data-acquisition systems for real-time measurements at the appropriate level of sophistication for a variety of uses in teaching of physics in the classroom and the laboratory.
- support curricula that teach physics with an appropriate diversity of methods, including hands-on approaches, that encourage critical thinking and help students understand how physics is relevant to their local cultures and to a sustainable future for humankind.

To help give effect to the resolution, the IUPAP General Assembly also supported the suggestion of ICPE that

- special sessions be organized on educational aspects of hands-on learning, experimentation, and appropriate assessment, in discipline specific conferences of the IUPAP commissions.
- multinational collaborations and workshops be organized for design and development of resource material for active learning and laboratory work; and further, dissemination through professional training of physics educators.
- electronic resource centres be established for exchange of ideas about local initiatives, teaching materials, prototypes of "hands-on" equipment, in particular those that can be locally adapted for construction by the teachers and their students, to serve a variety of educational needs in diverse cultural contexts.

The adoption of this resolution is a milestone that recognizes the importance of dissemination of best practice in physics education and reiterates the urgent need to give a boost to physics education if research in physics is to thrive.

Promoting active learning: an example of praxis

A concerted effort has been made to implement the WCPSD Action Plans by all the sponsoring organizations and key players. Workshops to promote Active Learning have been on top of the agenda.

UNESCO Workshops on Active Learning in Optics and Photonics (ALOP): Within the framework of the UNESCO program for basic sciences, an international team of resource persons, led by Minella Alarcon has organized numerous workshops on Active Learning in Optics and Photonics (ALOP) in various developing countries such as Tunisia (March 2005); Morocco (Cadi Ayyad University, Marrakech, April 2006); India (Miranda House, University of Delhi, November 2006); Tanzania (Dar Es Salaam University, July 2007); Brazil (Universidade de São Paulo, July 2007); Mexico (Leon Guanajuato, November 2007); Argentina (2008); Mozambique (2008), and many more. The outreach till date is more than 600 teachers.

ALOP is a week-long workshop designed for teacher trainers from developing countries focusing on optics and photonics. This is an exciting area of study enabling research on the frontiers with capstone applications in diverse fields using high end technologies. Starting from introduction to light, geometrical optics, optics of the eye, interference, diffraction and spectroscopy, the workshop coherently introduces advanced topics of atmospheric optics and optics in communication. Participants are challenged with intriguing questions on how information is carried by light waves, how light is recorded as an electrical signal, how optical fibres transmit information and what internet communication is all about. The activity based curriculum includes a well-structured training manual. Each module embeds hands-on experiments and activities that can be locally fabricated or set up using easily available inexpensive materials. Each module also integrates concept questions and provides the PER-based Light and Optics Concepts Evaluation (LOCE) tool to measure student learning. The end-of-unit topics motivate teachers and their students to learn basic physics in order to understand new areas of science and technology that are highly valued in the global economy. For better dissemination, the ALOP Manual has been translated in other languages such as Spanish, Portugese and French to widen outreach, especially in Latin America and Africa.

The ALOP workshop serves as a paradigm for efforts to promote throughout the world the educational goals set by WCPSD (Laws, 2008).

THE PHYSWARE INITIATVE

As a direct follow-up on the WCPSD and IUPAP mandate, WCPSD co-Chairs Pratibha Jolly, Priscilla Laws joined by Dean Zollman and Elena Sassi proposed the idea of organizing a series of *Educate the Educator* workshops titled *Physware*.

Mission: The core mission of the *Physware* initiative is to impact quality of physics education at the secondary and undergraduate level through collaborative workshops carefully designed to promote active learning methods using prototypes of affordable hands-on equipment that can be locally adapted for construction by teachers and their students throughout the developing world. An important facet is simultaneously providing an exposure to appropriate technologies, computer-based tools and open source softwares for enhancing conceptual understanding, in tune with changing aspirations of developing communities. The goal is to integrate hands-on activities within carefully crafted active learning instructional materials so that these can be used effectively.

The *Physware* initiative aims to go beyond its workshops by also providing a forum to physics educators to share experiences and exchange ideas about dissemination of active learning methods. It is hoped that they will lead similar efforts in their local regions. In the long term, *Physware* envisions creating and strengthening regional and international networks of physics educators who can adopt global best praxis anchored in physics education research — giving due credence to locally meaningful adaptations situated in local contexts.

PILOT WORKSHOP: PHYSWARE 2009

Within this framework, the first *Physware* was held at ICTP, Trieste, from 16 to 27 February 2009 with above listed four as co-directors and Joseph Niemela from ICTP as local co-ordinator and facilitator. Financial support primarily came from ICTP.

Theme: Teaching of Newtonian Mechanics was chosen as the topic for the first workshop.

Participants: In addition to the ICTP publicity network, a concerted attempt was made by the directors to outreach physics education communities by distributing the workshop poster at several physics education events across the world, posting it on pertinent websites and newsletters such as that of ICPE. A record number of more than 200 applications from 48 countries were received, posing a challenge to selection. A rigorous scrutiny enabled selection of 32 participants from 27 countries spread across Africa, Asia, Latin America and Europe. The participants represented a multicultural but eclectic group of extremely talented and innovative physics teachers, teacher-trainers and administrators — some bearing multiple responsibilities. Preference was given to those with demonstrated expertise in developing hands-on activities and potential for assuming leadership role in organization of similar workshops.

Technical Sessions: The two week workshop (with 10 working days) was structured to have four blocks of one hour forty five minutes on each day. Additionally, seven days included a two hour post dinner block to accommodate poster sessions and special discussions. At the outset the participants were given an exposure to seminal physics education research in the context of mechanics. Early discussions compared and contrasted traditional teaching methods with strategies underpinning enquiry-based active learning environments. Participants were introduced to research on students' conceptions of mechanics, research-based concept tests, diagnostic tools and learning cycles that promote active engagement in the context of teaching-learning of kinematics and dynamics. The workshop manual drew on eclectic resources drawn from University of Washington Tutorials, Workshop Physics, Interactive Lecture Demonstrations, Learning with Physics Suite, The AMSTEL resources, Naples PER group material, the Uganda Project and University of Delhi Interactive Lab Tutorials (Redish, 2003; McDermott & Shaffer, 1998; Sokoloff & Thornton, 1999, 2004; Laws, 2004; Laws & Teese, 2009; Jolly & Bhatia, 2001).

Low-cost Locally Fabricated Set ups: The first week modules embedded activities designed using locally available materials. This mandate led to development of several rough and ready set ups and innovative measurement procedures. For instance, different length pendulums were used as clocks to measure time in arbitrary units. Pendulums were fabricated using walnuts, metal nuts, lengths of vine or thread. These were used variously to investigate oscillatory motion and the effect of changing various physical parameters. A mahogany flower pendulum was used to study damping as petals were gradually peeled off to change its shape, and then put back so that the mass was restored but not the shape. There was much experiential learning with kinesthetic involvement as distance was measured in arbitrary units, innovative clickers were used for equal interval timing to graph motion. The do-it-yourself approach led to fabrication of an interesting range of hand-made carts, dynamic tracks and frictionless surfaces. Battery operated toy fans mounted on carts generated interesting variations in motion. Furniture was juxtaposed to study rolling down makeshift inclined planes. Force was measured with rubber bands and then springs. It was found that acceleration due to gravity could be measured fairly accurately merely by timing the fall of a coin. Later the ubiquitous cell phone provided a convenient mechanism for accurate measurement of time.

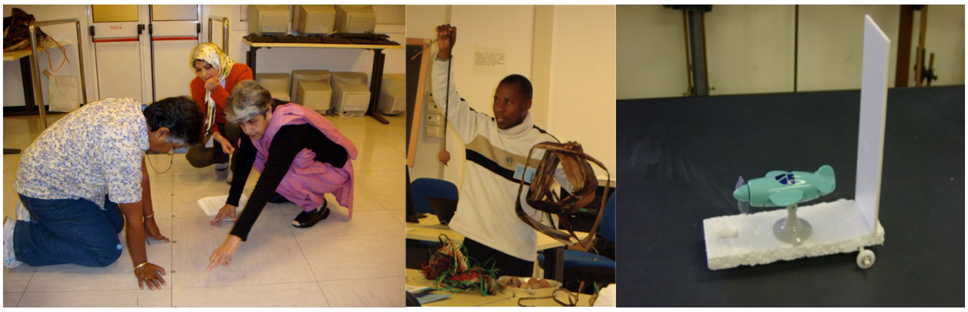


Figure 1: Learning with low cost alternatives

Appropriate Technology-mediated Learning: In the second week, the participants were given a rigorous exposure to appropriate technologies and computer-based measurement. These included use of motion and force sensors, photogates; data and graphical analysis software; and free/open source software. Powerful video data analysis tools were used to analyze video clips of interesting motions such as that of a basketball thrown by a player in action. Participants also created short video clips of objects in motion. A session was devoted to how simulations can be integrated into the learning cycle to enhance conceptual learning. Discussions veered on need to judge if a particular simulation is an appropriate representation of the phenomena or experiment, if it can replace the engagement with the physical world, and how best to judiciously overlay a simulation on a hands-on activity.

The pedagogic strategy of introducing technological refinement only after having worked without it made the participants compare and contrast the two approaches. On one hand – recalling the great excitement of designing and fabricating one's own minimalistic experimental set up — they were able to realize how much conceptual learning can take place without access to sophisticated instruments. On the other hand, they could appreciate the enabling role of technology in enhancing conceptual learning, visualization, and rigorous in-depth investigations.

Expanding Horizons: Two special sessions were organized to introduce the participants to virtual instrumentation project ongoing at the ICTP M-Lab; and construction of communication networks using low-cost wireless technologies. The contemporary value of demonstrations generated a great deal of interest. In another session, the participants evaluated features of low-cost computers, including the much in news "one hundred dollar" computer from MIT.

Projects: The touchstone of *Physware* was collaborative work on projects in small groups. This generated a vibrant atmosphere simulating an effective active learning environment that can be replicated for students. Following the structure of the workshop, the projects in the first week entailed creative use of low-cost materials in active learning of topics of core importance in mechanics. The group presented the work through posters. In the second week, projects judiciously used appropriate computer-based technological tools. As many as fourteen projects were carried out in a span of a day. All the groups made power point presentations. As an illustrative example, one of the projects evaluated effectiveness of different technologies to measure the time of free fall. This entailed real time data acquisition using a motion sensor, video capture and a cell phone as a timing device. Subsequently this work was refined and published (Rocha et.al., 2011). It is interesting to note that the collaborating team had members from five different countries, namely, Brazil, Columbia, Venezeuela, Argentina, and Cameroon. Without *Physware*, such a group would never have found an opportunity to collaborate and publish jointly.

Figure 2: Comparing three different technologies to measure fall of an object

Outcomes: A measure of the success of the pilot workshop was the immense enthusiasm and diligence with which the participants worked until late at night as sessions stretched to 10 pm on most evenings. Feedback of the participants on formal evaluation forms was extremely positive on all counts.

Figure 3: The Aha Moments!

Figure 3 captures the spontaneity of the Aha Moments! This stands testimony to the uninhibited active engagement and joy of learning as the teacher participants assumed the role of students at the workshop.

Sharing Concerns: Early in the workshop, the participants were encouraged to participate in evening poster sessions where they could present illustrative extramural and synergetic activities they were engaged in; innovative projects undertaken; interesting informal learning initiatives; or some aspect of physics education in their home institution or country. This served the dual purpose of breaking the ice and identification of areas of mutual interest and work. The presentations also served to identify the large common denominator of problems faced by all countries.

Evening discussion sessions spanned a wide range of topics. For instance, the issue of under representation of women in physics was discussed. Participants shared informal statistics, country reports, personal experiences and successful initiatives to reverse the trend. The organizers shared the proceedings and resolutions emanating from the three IUPAP sponsored International Conferences on Women in Physics held at Paris 2002, Rio de Janeiro 2005 and Seoul 2008. As a natural extension, issues of multicultural and multiethnic classroom followed.

Towards Advocacy: An important development was that then Director ICTP, K Sreenivasan, remained proactively tuned in and spent several hours interacting with the participants, formally and informally. He listened carefully to the problems of physics education in developing countries and the need for ICTP to initiate programs in the area. The participants functioned well as an advocacy group and urged ICTP to continue support to *Physware* and further, facilitate a web-based system for sharing resources. The group also deliberated separately to provide inputs to an action plan for consolidating *Physware* as a series of global and regional workshops.

Leveraging Social Technologies: The Directors created a Wiki before the workshop for pre-workshop interactions to understand participants' background, needs and to set the agenda. The workshop related information and resource material was made available on the *Physware* website created by ICTP on their portal (Physware workshop, 2009). However, the highlight of the workshop was the creation of a *Physware* Discussion Group and a Blog during the workshop by one of the participants. She volunteered to be the webmaster and ably led the participants through a special tutorial on how best to use the blog. Others were quick on uptake and throughout the workshop used the sites for exchange of information, resources and discussion on several threads. Social technology became the enabling lifeline for personal bonding, group communication and collaborative professional growth. Participants were quick to realize that the virtual forum would help them overcome geographical divide and personal isolation; it would help them sustain the dialog and the work begun.

Motivating Regional Leaders: As envisioned, the pilot workshop successfully established a primary network of outstanding physics teachers from developing countries with an overview of validated best practices in physics education. These educators expressed enthusiasm about sharing their *Physware* experience and building on it to find solutions to regional and local physics education problems. Since then, some participants have taken a lead role in organizing active learning workshops in their region. For instance, Julio Benegas from Argentina led the Latin American Regional South Cone Workshop on Active Learning in Mechanics at Córdoba in June 2009 (Benegas, 2009). He has taken a lead role in creating a strong collaborative network in the region and organized several other programmes.

INSTITUTIONALIZING PHYSWARE

It was felt that the *Physware* initiative can be sustained and impact physics education only if it is institutionalized. The original sponsors IUPAP — working through its Commission on Physics Education (ICPE) – and ICTP were seen as the appropriate stakeholders to take the lead role.

Indeed, IUPAP and ICTP share common interests in promoting scientific advancement and high-quality science education in physics and its applications. IUPAP is serving to advance the worldwide development of the physical sciences and to contribute to the application of physics toward solving problems of concern to humanity. The mandate of ICTP includes fostering high-level scientific research in developing countries by providing world-class opportunities for both scientists and students at the post-graduate level. ICTP's role has been pivotal in training and capacity building for strengthening scientific enterprise. It has been continuously developing high-level scientific training programmes with sustained attention on the changing needs of developing countries recognizing that good education is critical to scientific and technological development. Then both organizations have a special focus on the needs of the countries where physics is less developed. A fruitful cooperation between the two institutions in furthering the cause of physics education would serve their common interests better.

In October 2009, the President of IUPAP — acting on behalf of ICPE — and the Director of ICTP signed a Memorandum of Understanding (MoU) for a five year action plan. Under this, it was envisaged that ICPE and ICTP would cooperate in organizing the *Physware* Educate the Educator series of collaborative workshops to promote active teaching-learning in undergraduate physics in the developing world. These would be modelled on the *Physware* pilot workshop organized at ICTP in February 2009. The goal would be to organize five annual workshops with a developing country and ICTP Trieste alternating as venues. ICPE would be a coordination committee. Each year representatives of ICPE and ICTP, jointly with others as desired, would confer to discuss the funding, venue, organization, experts and resource persons and participants. For the workshops to be held at Trieste, ICTP would make an in-kind contribution and leverage the facilities and expertise in fundamental and emerging physics research available at ICTP, including the facilities and expertise of the Multidisciplinary Laboratory and the Science Dissemination Unit. For the workshops to be held outside Trieste, ICTP would provide institutional contacts for hosting workshops in developing countries and use its resources to provide proper publicity for events. These workshops would focus on innovative physics teaching using contexts of specific relevance to the development of the region in which it is held.

It was clear from the outset that a 5-year effort of this nature could not be undertaken within the existing financial structure of only IUPAP or ICTP. Thus it was mandated that ICTP and ICPE would together solicit funds from both public and private sources with the goal of eventually getting governments and regional professional organizations to take major financial responsibility for the workshops in their own territories. In fact, raising grants has been a far bigger challenge than first anticipated. Despite the commitment to a common cause reflected in the MoU, neither IUPAP nor ICTP was able to allocate an annual budget to the proposals submitted.

PHYSWARE 2012

Having played the key role in conceptualizing *Physware* and steering the MoU, the author took up the challenge of raising grants to organize the next workshop in Delhi at her own institution from 26 November to 7 December 2012. The venue was the D S Kothari Centre for Research and Innovation in Science Education (DSKC) established at Miranda House. As committed in the MoU, ICTP sponsored the workshop with partial funding and provided secretarial support from its office in Trieste. The host institution raised funds locally from several government agencies to cover the significant cost of running a two week residential programme.

Theme: The workshop focused on teaching-learning of Electricity and Magnetism in introductory courses.

Participants: The programme was widely advertised using ICTP's official network and also through local efforts. It drew about 200 applications from 44 countries across the world. The directors scrutinized each application with great care to constitute a multicultural group of 46 physics educators from 12 countries, each with an extremely interesting work profile. This group included 25 international participants. Optimising available funds, preference was given to those from neighbouring countries of South Asia, East Asia and Africa, with largest groups coming from Pakistan, Sri Lanka, Philippines and Nigeria. In addition, there were 21 participants from India — drawn from 10 different federal states — representing the vast geographical, socio-cultural and ethnic diversity of pluralistic India. There was no registration fee. All participants were provided full or partial travel support; complete local hospitality and accommodation on campus for two weeks; and workshop material.

Immersion in an Actual Active Learning Environment: Miranda House, college for women at the University of Delhi is amongst the premiere educational institutions in India. It has two extremely well-equipped large undergraduate physics laboratories. In addition, it has two project-based learning studios fashioned after Workshop Physics programme established by Priscilla Laws at Dickinson College, US. The physical layout and design of work tables encourages collaborative work. The labs have networked computers with high bandwidth access to internet and additionally, access to wi fi available across the campus. The college has been leading efforts in developing innovative lab curriculum that integrates activities ranging from no-cost, low-cost, locally fabricated set ups to sensor-based real time measurements using computers and handheld devices as data acquisition systems. On one hand, the college is able to pull out bits and pieces of odd materials to put together string and sticky tape experiments with great ease. On the other hand, it has available multiple sets of computer-based systems from Vernier, PASCO, COACH and Labview allowing several groups to work simultaneously on a desired activity. Additionally, the college has a large contingent of laboratory support staff who is well trained to source material locally and find innovative solutions for hands-on activities. They are always ready to run down to the local hardware shop or the electronic components bazar to procure items not initially anticipated for use. The international directors were delighted to see how quickly ideas translated into activities. All these facets combined to give the Delhi workshop a hands-on minds-on edge in contrast to the pilot workshop at Trieste where instruments had to be predecided and ported in limited quantities from elsewhere causing major limitations in scope. More importantly, the location was not a simulation but an actual active learning environment in a college primarily devoted to teaching. The story of how the college incrementally reinvented its environment from traditional to innovative proved to be motivational. Participants saw much that could be easily replicated.

Technical Sessions: *Physware* 2012 followed the framework of the earlier pilot workshop. However, there were qualitative differences and advantages that accrued from the choice of venue. These made a huge difference to the academic level of the workshop.

Curriculum: Structured course material was put together as a manual. It unfolded a coherent progression of key concepts over two weeks, as summarized in Table 1.

Table 1: Workshop Course Structure and Concepts Covered

Week 1	**Week 2**
Electrostatics	Magnetism
Verification of Coulomb's law	Motion of Charges/ Wires in Magnetic Fields
Electric Field Hockey and Rutherford Scattering	Magnetic Field around a Current Carrying Wire
Gauss Law and Faraday's Pail	Motion of Magnets and Coils
Representations of Electric Fields	Electromagnetic Induction
Representations of Electrostatic Potentials	Faraday's Law, Eddy Currents
Basic DC Circuits	Energy Flow in a Simple Circuit
Basic Capacitor Circuits	Electromagnetic Waves
Active Learning in Advanced Courses	Active Learning in Advanced Courses
Projects	Projects

Judicious use was made of materials selected from validated physics research-based curriculums to exemplify active learning of the outlined concepts, foremost amongst them Real Time Physics. Real time measurements and video analysis tools were introduced. An associated reading list drew from seminal work of leading physics education research groups (McDermott & Shaffer, 1992; Shaffer & McDermott, 1992; Knight, 2004; Berg, 2012; Meltzer & Thornton, 2012). Again, the entire material was uploaded on the ICTP *Physware* website and also on a Google Group created by the Directors for the purpose.

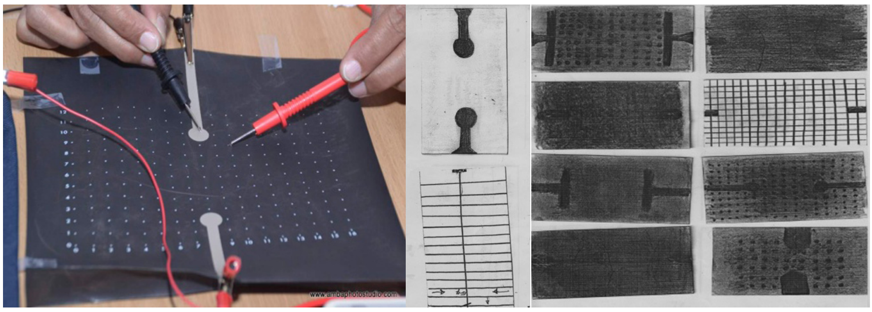


Figure 4: Designs for zero cost carbonized paper with electrodes to plot equipotential "surfaces"

The Jugaad Model of Innovation: The activities leveraged the facilities on hand. A fairly low-cost kit was assembled. In several sessions, a motley collection of wires, magnets and other sundry items were laid on the table and participants asked to demonstrate a principle or concept. They were invariably able to assemble a clever experiment with great dexterity. In India, the art of improvising an ingenious solution with whatever is available is called *Jugaad*. It is widely prevalent in all spheres of life. In translation, the word would translate as *jietinho* in Brazil, *jua kali* in Kenya, *zizhu chuanxin* in China and *systéme D* in France. As an aside, it is pertinent to share six principles of *Jugaad* as identified by authors of a book by that name (Radjou et.al., 2012). These are, to (i) seek opportunity in adversity, (ii) do more with less, (iii) think and act flexibly, (iv) keep it simple, (v) include the margin, and (vi) follow your heart. The last two pertain to the social dimensions of innovation and can help a curriculum developer to extrapolate what would be most appropriate in different settings. In science classes, the *Jugaad* model allows one to put together the so-called string and sticky tape experiments very innovatively. Of course, *Jugaad* can often acquire pejorative connotations — it cannot be the sole way of doing things. As and when needed, appropriate level of sophistication and rigour in design must be introduced.

An activity to explore equipotential "surfaces" in two dimensions uses a special conducting paper with electrodes painted on it. Equipotentials are then used to construct field lines. This paper could not be procured in Delhi. One of the lab staff fabricated carbonized paper in a jiffy by rubbing ordinary graphite pencil on a small sheet of paper. Electrodes were also created using the same technique. The participants took instant liking to the idea. Playing around, several innovative ways of shading and growing conducting electrodes were tested. A variety of miniaturized conductive configurations were created using the backside of discarded visiting cards (Figure 4). The exercise generated much excitement amongst participants as discussions began from the concept of a resistance before veering to the task on hand. Other examples abound. A common strategy adopted was to place a few items on the table and ask, what can you do with this stuff? For instance, given a screw, a tiny magnet, a bit of wire, a 1.5 volt battery, it was interesting to trigger imagination and see if a motor could be configured.

Pedagogic Strategies: Participants worked in collaborative groups of 4 to 5 assuming the role of learners with great enthusiasm, negotiating each activity with animated discussions. As stated before, the suggested hands-on activities were designed so that they could easily be replicated in any teaching-learning environment and embedded in any teaching style. The emphasis was on evoking pedagogic strategies which can effectively convert any classroom into an active learning environment. Participants were given exposure to the well-known strategy of using Interactive Lecture Demonstrations (ILD), known to be effective in large classrooms. They were also asked collaboratively to design and present ILDs to communicate a chosen concept. Honouring the immense talent pool, the participants were given freedom to improve suggested set ups, design new activities *ab initio* and suggest new approaches in all sessions while respecting the time schedule. This resulted in many innovative additions to the repertoire.

Enhancing Conceptual Learning: One of the key objects of *Physware* 2012 was to introduce the participants to Physics Education Research in the context of the theme of the workshop and the implications for teaching-learning. The directors presented a case study on how the Electric Circuit Conceptual Evaluation (ECCE) was developed based on research. Participants were also introduced to other Physics Education Research-based instructional materials with particular focus on conceptual evaluation on electricity and magnetism. Illustrative examples included those from Real Time Physics and the Brief E&M Assessment (BEMA) tool, which was used extensively throughout the workshop (Ding et.al., 2006). Select questions from BEMA were embedded in the sessions at appropriate points in almost all sessions, drawing attention to concepts which research shows pose challenge to students learning. All hands-on sessions were followed by in-depth discussions between the entire group and a summative exercise led by the directors.

Expanding Horizons: An invited talk by a young Indian physicist who has been contributing to the ongoing experiments at CERN introduced the participants to particle accelerators and experiments in high energy physics. He spoke on 'Observation of a New Boson at the World's Highest Energy Accelerator' presenting the latest results from CERN on discovery of Higg's Boson. Participants also visited the National Science Centre at Delhi to look at the various interactive models, particularly in the context of the theme of the workshop.

Several sessions were devoted to introducing participants to web based repositories of online resources, open source software, simulations, visualization tools etc. In particular, participants were introduced to the comPADRE and PER User Guide (comPADRE, n.d.). They also explored extensively the PHET Interactive Simulations from the Colorado Project, the MIT Technology Enhanced Active Learning Studio Project (TEAL), the online course on Visualizing Electromagnetic Fields. They discussed how best to integrate the resources in their own teaching. Dean Zollman introduced the participants to his work on Modern Miracle Medical Machines, and particularly medical imaging. A simple analogous simulation using magnetic compasses introduced the complex concept of magnetic resonance imaging. This was followed by an interesting interactive talk on Alexander Graham Bell and Medical Imaging (Kansas State University Physics Education Research Group, 2010). The high level of interest and understanding exhibited by the participants led to fine tuning the depth to which each concept was discussed. Departing from the original plan, the directors introduced sessions devoted to pen and paper tutorials for advanced students. For example, in week one, a tutorial from Oregon State University, "Paradigms in Physics: Designing an Electric Field" was introduced. In Week 2, advanced tutorials were on Faraday's Law and on use of Poynting Vector.

Projects and Presentations: The most exciting feature of the workshop was the collaborative work on projects and the opportunity given to each collaborating group to present their work, incorporating the hands-on demonstration with a powerpoint presentation. Participants displayed immense creativity. Each presentation evoked vibrant discussion. Examples include design of a Gravimeter using magnetic induction for accurate measurement of acceleration due to gravity.

Challenges: The directors were kept on their toes and required to continuously think out of the box. They needed a high level of competence to meet the challenging questions posed by a well prepared group of physics educators, who were also deeply committed and deeply engaged to the task on hand. Ultimately, no question was too difficult as answers emerged from within the group through Socratic dialogs. All this became possible because of the collaborative spirit underpinning all activities and the knowledge pool available in the collective. This enhanced the confidence of each participant.

CONCLUSIONS AND FUTURE PLANS

A significant milestone in international cooperation, the *Physware* workshops described herein provide a sustainable model for capacity building of large number of physics educators, especially in the developing countries. *Physware* has successfully established a primary network of outstanding physics teachers who have an overview of validated best practices in physics education. These educators are enthusiastic about sharing their knowledge of active learning using low-cost materials and emerging technologies. Given that training and capacity building of physics educators is seen to be the critical first step if young students are to be motivated to pursue careers in physics or contribute to development as envisioned by their national goals, *Physware* promises to be amongst the most important activities of ICPE in the coming years.

Challenges: Capacity building of educators involves a complex interplay of many factors. Each step in the process of pedagogic innovation, dissemination and diffusion of innovation brings its own unique challenges. The recurring question is how to mainstream innovation. This requires transforming ecosytems. No easy task, this is at best a journey and a work in progress. Very frequently, participation in an innovative programme is a mere spike in the career of the educator. Frequent exposure to best praxis in a variety of new contexts and sustained support during transformative periods is essential. Long term impact can only be assessed on the basis of how well the individual is (i) able to adopt or adapt the new skills and pedagogic knowledge; (ii) able to apply these to improve her own classroom practice in her own home institution despite constraints of existing educational framework; (iii) disseminate the experience gained to create a critical number of like-minded practitioners who can impact the institutional practices in the long term.

The ultimate success of the *Physware* initiative will depend on growing the circle of influence along three important dimensions, namely,

(i) the range and depth of content — it is important that subsequent *Physware* workshops should cover more and more topics of physics for comprehensive impact.

(ii) the quality of content — it is important that each *Physware* workshop should be iteratively refined taking into account the feedback of the participants and further fine tuned to be compatible with local needs and contexts.

(iii) the scale of educational outreach — it is important that a significantly large number of educators in any region should be exposed to the new pedagogies, receive adequate training, and assume the role of regional leader or agent of change to provide opportunities to more and more educators.

Replicable Workshop Model: The *Physware* workshop model has salient features that make it amenable for wide scale adoption. It:

(i) uses curriculum and resource material easily adapted to the needs of any region;
(ii) uses low-cost equipment and locally available technologies;
(iii) introduces appropriate technology and applications of relevance to the work place, thereby motivating interest;
(iv) provides ways to integrate topics in contemporary research or applications of these topics thereby introducing participants to teaching fundamental new physics within the context of contemporary pedagogy;
(v) employs activity based pedagogic methods proven to be effective through educational research;
(vi) assesses participant needs and attainment of workshop goals through pre-workshop discussions, on-site feedback and post-workshop evaluations;
(vii) organizes collaborative groups to enhance professional development opportunities for physics educators who teach in developing countries;
(viii) identifies regional leaders who can in turn organize regional versions of *Physware* workshops thereby reaching out to a critical number of physics educators necessary for affecting change.

Both the *Physware* workshops described herein have been hugely successful in achieving their objectives. They addressed two different themes and make available well-structured curricular material along with an accompanying activity kits. The same model can easily be extended. It is hoped that each subsequent workshop will address a new topic and create several thematic *Physware* Manuals with Activity Kits.

Action Plan: The ICTP-IUPAP MoU five year action plan mandated a structured plan for scale up of the Physware initiative and regular organization of the workshops. Figure 5 depicts the vision.

The idea was to develop workshop manual and kits on at least five different topic areas such as Mechanics, Electricity & Magnetism, Waves and Oscillations, Optics,

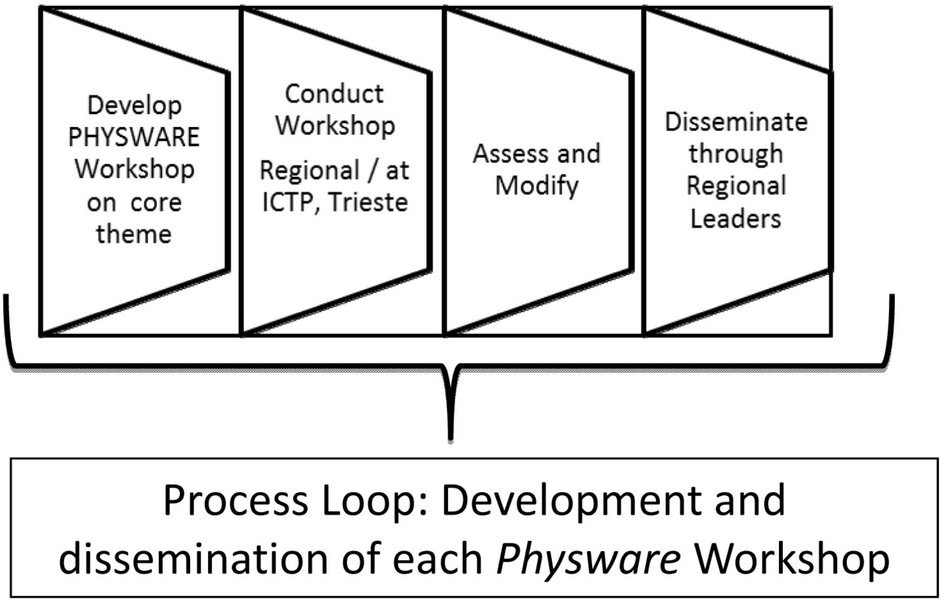


Figure 5: Action Plan for sustained development and outreach through workshops

and Thermal Physics. A different international team of directors that has broad experience with teaching environments, cultural differences and the educational needs of peoples from many nations would be responsible for each theme. Once executed, the material would be continuously upgraded based on feedback. It would also be made available to participants with demonstrated leadership qualities so that they could conduct similar workshops in their own regions. Further, it was suggested that a special session on Physware should be organized at each ICPE conference to share, evaluate progress and plan future workshops. All this would have a cascading effect and scale up outreach.

Multi-institutional Support: Although *Physware* is currently the flagship programme of ICPE, ideas have not translated to action as planned. The single reason for this has been lack of adequate dedicated funds. A long term effort of this nature needs multi-institutional support, public and private sponsorship for organization of at least the first set of workshops with the goal of eventually getting governments and regional professional organizations to take major financial and organizational responsibility for additional capacity building workshops in their own territories. Pending such support, it would be prudent to use developing countries as venue with host institutions taking the responsibility of raising funds locally and ICTP providing partial financial support and logistic support.

Building a *Physware* Community of Practice: Another important clause of ICTP-IUPAP MoU that has so far remained essentially dormant is the commitment to develop a *Physware Resource Website* for physics educators. It was envisaged that this web based repository of high quality physics education resources would serve the needs of those from countries where examples of best practice are not easily available; consolidate the gains of *Physware* workshops; and give sustained support to *Physware* participants for continued sharing of efforts through structured communication. Going beyond, it is crucial to seed formation of a *Physware Community of Learning and Practice* if participants are to overcome isolation in their home institutes or countries and continue collaborations forged at the workshop — while working in their respective countries. The aim would be to undertake sustained computer supported collaborative work to produce concrete outcomes that can be shared globally to impact regional practice of physics education in the long term. No easy task, creating a successful *Physware* community would require a dedicated facilitating team that is knowledgeable about physics education and teacher education. It remains to be seen if the collaborating organizations led by ICPE can deliver this dream.

Acknowledgement

It is a pleasure to thank the *Physware* co-directors Dean Zollman, Priscilla Laws, Elena Sassi, and ICTP coordinator Joe Niemela for an enjoyable and fruitful collaboration. The Delhi workshop would not have been possible without the support of Miranda House staff, particularly Mallika Verma, the local coordinator of *Physware* 2012. It is also a pleasure to acknowledge all the *Physware* workshop participants who are individually responsible for the success of the initiative.

Finally, I dedicate this paper to the memory of Elena Sassi — friend, mentor and co-director who unfortunately is no longer with us. The Delhi *Physware* workshop was probably her last academic engagement, her last adventure. Vivacious, full of energy, she was always surrounded by *Physware* participants wanting to learn more from her. She will be deeply missed.

REFERENCES

Benegas, J. (2009). *Report of the 2^{nd} Regional South Cone Workshop on Active Learning in Mechanics (AAMe- Córdoba'09) and the 2^{nd} Regional South Cone Conference on Active Learning in Physics (CRAAF-2).* Available at http://journal.lapen.org.mx/sep09/31_LAJPE_288_Julio_Benegas.pdf

Berg, R. E. (2012). Resource Letter PhD-2: Physics Demonstrations. *Am. J. Phys.* 80, 181.

comPADRE. (n.d.). Available at http://www.compadre.org

Ding, L., Chabay, R. & Sherwood, B., et. al. (2006). Evaluating an electricity and magnetism assessment tool: Brief Electricity and Magnetism Assessment. *Physical Review Special Topics — Physics Education Research* 2, 010105.

IUPAP Website. (n.d.). Available at http://www.iupap.org

Jolly, P. (2002). An Indigenous Process of Pedagogic Innovation: A Case Study on Curriculum Development, *AI & Soc.*, 16, 148–162.

Jolly, P. (2001). A Refresher Course in Physics Education: Training College Teachers to do Classroom Research. In R. Pinto & S. Surinach (Eds), *Physics Teacher Education Beyond 2000* (249–252). Elsevier.

Jolly, P., Bhatia, V. B. & Verm, M. (2001). Developing a Research-based Laboratory Curriculum for College Physics (workshop). In R. Pinto and S. Surinach (Eds), *Physics Teacher Education Beyond 2000* (319–324). Elsevier.

Jolly, P. & Laws, P. (2006). World Conference on Physics and Sustainable Development, *ICPE Newsletter*, 51(3).

Kansas State University Physics Education Research Group (2010). Modern Miracle Medical Machines, http://www.phys.ksu.edu

Knight, R. D. (2004). *Five Easy Lessons — Strategies for Successful Physics Teaching.* Addison Wesley.

Laws, P. W. (1997). Millikan Lecture 1996: Promoting active learning based on physics education research in introductory physics courses, *Am. J. Phys.* 65, 14–21.

Laws, P. W. (2004). *Workshop Physics Activity Guide: The Physics Suite.* Volumes 1 to 4, John Wiley & Sons, Inc.

Laws, P. W. (2008). A Lens into the World, *AAPT Interactions*, 21–23.

Laws, P. W., Teese, R. B. & Willis, C. W., et.al. (2009). *Physics with Video Analysis.* Vernier Software & Technology.

McDermott, L. C. & Redish, E. F. (1999). Resource letter PER-1: Physics Education Research. *Am. J. Phys*, 67, 755–767.

McDermott, L. C. & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *Am. J. Phys.* 60 (11), 994–1003.

McDermott, L. C. & Shaffer, P., et.al. (1998). *Tutorials in Introductory Physics.* Prentice-Hall Inc.

Meltzer, D. E. & Thornton, R. K. (2012). Resource Letter ALIP-1: Active-Learning Instruction in Physics. *Am. J. Phys.* 80, 478.

Physware workshop (2009). ICTP, Trieste, Italy, Available at http://cdsagenda5.ictp.trieste.it/full_display.php?ida=a07137

Radjou, N., Prabhu, J. & Ahuja, S. (2012). *Jugaad Innovation: A Frugal and Flexible Approach to Innovation for the 21st Century.* Random House India.

Redish, E. F. (2003). *Teaching Physics with the Physics Suite.* John Wiley & Sons, Inc.

Rocha, F. S. D. & Fajardo, F., et.al. (2011). Using "Student Technology" in Introductory Physics: A Comparison of Three High Tech Tools to Study Falling Objects. *The Physics Teacher*, 49, 165–167.

Science (2013). *Grand Challenges in Science Education.* Special Issue, 340 (6130).

Sokoloff, D. R., Thornton, R. K. & Laws, P. (1999, 2004). *RealTime Physics: Active Learning Laboratories: The Physics Suite.* Volumes 1 to 4, John Wiley & Sons, Inc.

Sokoloff, D. R. & Thornton, R. K. (2004). *Interactive Lecture Demonstrations — Active Learning in Introductory Physics.* John Wiley & Sons, Inc.

Shaffer, P. S. & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of Instructional Strategies. *Am. J. Phys.* 60 (11), 1003–1013.

PRATIBHA JOLLY
Miranda House, University of Delhi, India

Scientia in educatione 8(Special Issue), 2017
p. 79–100
ISSN 1804-7106

Active Physics Learning: Making Possible Students' Cognitive Growth, Positive Emotions and Amazing Creativity

Josip Sliško

Abstract

It is now well known that carefully designed sequences of active physics learning support students' comprehension of physical concepts and laws. If only this were its effect, active learning should replace lecture-based teaching and passive students' learning at all educational levels. Fortunately, the impacts of active learning experiences in students are much broader. In this paper I present a few examples of tasks that are suited for engaging students in active learning along with research-based and anecdotal evidence about effects of active physics learning on students' cognitive level, emotions and creativity.

Key words: active physics learning, self-regulated learning, cognitive growth, positive emotions, creative thinking, students' demonstrations of weightlessness.

INTRODUCTION

Our today's students will live and work in the world of learning organizations and knowledge-based economy that change faster and faster. Life-long learning is their destiny and only possible path towards new employment opportunities and a secure personal and professional future! But the learning is not only a personal need, it is also an economic necessity (Argyris, 1991):

“Any company that aspires to succeed in the tougher business environment of the 1990s must first resolve a basic dilemma: *Success in the marketplace increasingly depends on learning, yet most people don't know how to learn.*

What's more, those members of the organization that many assume to be the best at learning are, in fact, not very good at it.”

Only “knowledge workers”, whose role is to transform existing and emerging knowledge into new products and services, can satisfy such a necessity. The number and quality of “knowledge workers” affect the present and the future of institutions and companies (Drucker, 1999):

“The most valuable asset of a 21st-century institution (whether business or non-business) will be its *knowledge workers* and their *productivity.*

Knowledge work requires *continuous learning* on the part of the knowledge worker, but equally continuous teaching on the part of the knowledge worker.”

Becoming a “knowledge worker” is not a trivial task. It requires that one dominate many complex skills which can only be learned through adequate learning experiences (Drucker, 2005):

“Knowledge workers must, effectively, be their own chief executive officers. It's up to you to carve out your place, to know when to change course, and to keep yourself engaged and productive during a work life that may span some 50 years. To do those things well, you'll need to *cultivate a deep understanding of yourself* — not only what your strengths and weaknesses are but also *how you learn, how you work with others...*”

These complex skills, needed by “knowledge workers” and business leaders, are recently called “XXI century skills”. Tim Wagner (2008), considers them as “surviving skills” and includes among them:

- Critical thinking and problem solving; Collaboration and leadership;
- Effective oral and written communication; Finding and analyzing information;
- Curiosity and imagination.

Higher-education institutions have a very important social responsibility in education of “knowledge workers”, who should be prepared to face, not only today's known problems, but more future unknown problems which will appear in next decades (Jarvis, 2001; Graham, 2002) .

Keeling and Hersh consider that learning, needed by actual knowledge-based economy,

“...requires that students be fully engaged participants in a powerful intellectual, social, and developmental process. That process requires rigorous self-discipline, effort, and commitment; demanding well-trained teachers; an inspiring, motivating, and diverse curriculum; and an intentionally designed, challenging, formative, and supportive learning environment” (Keeling & Hersh, 2012: p. 20).

Nevertheless, the university teaching, even in the most industrialized countries like the USA, is slow and unprepared to react adequately to these urgent economic needs. Keeling and Hersh made a dramatic diagnosis of that situation:

“The truth is painful but must be heard: we’re not developing the full human and intellectual capacity of today’s college students because they’re not learning enough and because the learning that does occur is haphazard and of poor quality. Too many of our college graduates are not prepared to think critically and creatively, speak and write cogently and clearly, solve problems, comprehend complex issues, accept responsibility and accountability, take the perspective of others, or meet the expectations of employers. Metaphorically speaking, we are losing our minds.” (Keeling & Hersh, 2012: p. 1).

According to Keeling and Hersch, one of the main causes of this situation is teaching-centered culture of colleges and universities:

“Since teaching is what matters and what is measured, instruction is mostly lecture-driven and learning, to the extent that it occurs, is mostly passive, receptive enterprise. In other words, students should come to class, listen carefully, take good notes, and be grateful.” (Keeling & Hersh, 2012: p. 20).

LECTURE-BASED PHYSICS TEACHING: A PARADIGMATIC EXAMPLE, SOME LEARNING OUTCOMES AND THEIR CAUSE

The central element of “teaching-centered culture” is lecture-based delivery of the course content. It has its roots in medieval pedagogy, when it was the only possible way of passing knowledge from a teacher to students who lived in a world in which books were very rare and expensive. Times have changed drastically and access to printed and digital books increased dramatically.

Nevertheless, lecture-based teaching, complemented by recitation sessions for solving end-of-chapter problems and cookbook lab activities, is still dominating practice in physics education. Its colorful description was given some times ago (Gautreau & Novemsky, 1997):

“Stroll down the corridors of a typical college, and glance in some of the classrooms where freshman courses in physics or other technical areas are being taught. Chances are you will see something like the following. Instructors in front of their captive — but rarely captivated — audience are extolling, with various degrees of enthusiasm, the virtues of physics and solving the problems of the week. Seated obediently in uniform rows facing their leader are the “students”, vigorously scribbling in attempts to transcribe each utterance and every blackboard marking of the instructor. Eyes glaze as students try to avoid fading off.”

A paradigmatic example of this way of teaching, with the highest degree of instructor’s enthusiasm, might be a set of physics lectures delivered by MIT professor Walter G. H. Lewin in 1999. With YouTube revolution, their video versions became world - wide popular, attracting millions of viewers. Prof. Lewin loves physics, and enjoys sharing his love, both with students in lecture hall and the readers of his recent book (Lewin, 2012). While in lecture-hall, he talks eloquently and with a touch of gentle humor, draws nice sketches and schemes, writes many formulas and performs eye-catching demonstrations and experiments.

What are students doing during the lecture? They have to divide their attention between listening to the words said, copying into their notebooks what is written on the blackboard and watching what is Prof. Lewin trying to demonstrate. Being so, they are not given any opportunity to participate intellectually, by answering and discussing some professor's rhetoric questions (what will happen if I do that?) or formulating their own questions (why did you say that?).

The above description was derived from Prof. Lewin's lecture *"Weight, perceived gravity and weightlessness"* (Lewin, 1999), which was selected because I recently started to use the topic of weightlessness as a context to explore students creativity (preliminary results will be presented later in the article).

The 50-minute lecture has three main parts, carefully thought out and ordered: (1) concepts' introduction and application; (2) low-teach and high-tech classroom demonstrations of weightlessness; and (3) video presentation of weightlessness inside a plane in free (engines-off) parabolic motion.

The concept of weight is a very controversial one, having at least three different conceptualizations (Galili, 2001). Although Prof. Lewin recognizes it, saying explicitly that the weight is a non-intuitive and tricky "thing", he introduces it straightly (and unorthodoxly) as the upward force a scale exerts on the body being weighted (Figure 1). Such a definition strongly contradicts both students' previous intuitive ideas about, and learning experiences with the weight concept, but no opportunity is given to them to reconsider their ideas and experiences. Instead, a rapid exposition of a few applications of the weight concept is presented. Some of results, very likely paradoxical to students (bodies of *different masses*, connected by a string over a pulley, in an accelerated motion have the *same weight*), were elaborated and commented as being almost self-evident.

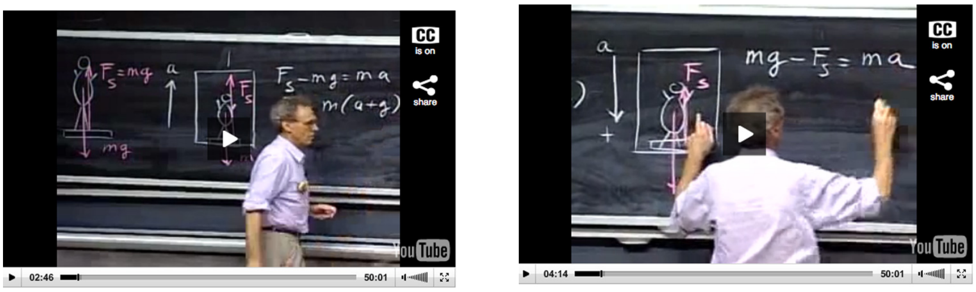


Figure 1: Prof. Lewin is introducing (verbally, visually and symbolically) the concept of the weight as the "force of scale" acting upwards on what is being weighing

Regarding controversial phenomenon of weightlessness, Prof. Lewin presents two types of demonstrations. The first type is low-tech carried out with a one — gallon water container. Initially, Prof. Lewin holds it in his hands, standing on the table (not very common position of a physics professor), and later jumps from the table, separating his hands slightly from the container (Figure 2). Not surprisingly, the container and Prof. Lewin fall in the same way, keeping their spatial configuration equal.

Figure 2: Prof. Lewin is performing a low-tech classroom demonstration of weightlessness of a gallon of water in free fall

The second type of weightlessness demonstration is a high-tech one, showing that two sensitive electronic balances, in free fall, don't register a weight of an attached object. The balances were designed and made at MIT.

It is very important to stress that, before performing both type of demonstrations, Prof. Lewin tells students what they are going to observe.

In the third part, students are shown videos clips about weightlessness experiences of persons on board of a plane moving along a parabolic path with engines off.

The lecture is surely music for the ears of those who already know a lot of physics and are able to understand fine conceptual details and subtle comments. What is unknown, at least to me, is how successful was MIT students' conceptual learning about the phenomenon of weightlessness, checked with right probing questions. Namely, in other educational contexts, students usually have difficulties to gain sound understanding of why and how the bodies behave as weightless (Galili, 1995; Gürel & Acar, 2003; Sharma et al., 2004; Tural et al., 2010)

Learning results of lecture-based teaching

In fact, poor learning about weightlessness is not an exception but rather a part of general learning outcomes of traditional teaching (Wieman & Perkins, 2005):

"...No matter how "good" the teacher, typical students in a traditionally taught course are learning by rote, memorizing facts and recipes for problem solving; they are not gaining a true understanding. Equally unfortunate is that in spite of the best efforts of teachers, typical students are also learning that physics is boring and irrelevant to understanding the world around them."

The diagnosis of unsatisfactory nature of learning results of lecture-based physics teaching can be stated in more specific terms (McDermott, 1991, 1993):

Conceptual learning is poor or absent.

Functional knowledge is not present.

Students are not able to apply high-order thinking procedures (like going from one to another representation or from abstract definitions and formulas to real word and back).

In addition, even in the domain of physics problem solving, a course part to which a considerable attention is given in traditional lectures, recitation sessions and exams, students mostly "conceptualize" it as a "plug-and-chug" game (Wells et al., 1995).

Why traditional lecture-based physics teaching does not work well enough?

The basic cause of failure is that this approach to teaching has behind it an erroneous theory of learning, which considers that the essence of learning is reception and memorizing of a clear instructional message. In other words, that approach does not take into account how humans learn (Bransford et al., 2001). It is almost a trivial fact that humans learn best by doing things, by making and correcting errors.

In order to do things perfectly, humans need to constantly improve their performances. Beside a lot of *step-after-step* practice, they also must think critically and creatively on what they do. It is well understood in sports and music. Nobody will learn to swim listening someone talking about swimming (and about Stokes' force) nor will someone learn to play violin listening someone talking about violin playing (and about Fourier transformations). Successful human learning is, in its very essence, an active process.

What is active physics learning?

Active physics learning (physics learning based on minds-on and hands-on activities) is gaining popularity in physics education, becoming a promising new paradigm which will, sooner or later, replace old paradigm codified in lecture-based teaching and passive learning. It is important to stress that active physics learning paradigm in physics teaching was not inspired and forced by general active learning movement in education (Bonwell & Eison, 1991; Harmin, 1994). Physics education researchers invented it while trying to solve above-mentioned annoying issue of unsatisfactory conceptual students' learning that results from lecture-based teaching.

There are now enough experimental evidences that physics researchers were successful in solving the issue. Namely, activity and inquiry-based learning approach is obviously better than lecture-based teaching regarding conceptual learning (Hake, 1998; Deslauriers et al., 2011; Scott et al., 2013) and problem solving performances (Thacker et al., 1994; Hoellwarth et al., 2005).

What does physics instruction that promotes active learning entail? There are some general answers to this question, such as:

"…Instruction involving students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time" (Meltzer & Thornton, 2012),

"…Instructional method that engages students to shift from a passive to an active role in the learning environment" (Prince, 2004).

More informative and practical instructional approach has, as its starting point, the following pedagogical belief:

In order to *learn* physics, students should *do* physics: observe, describe, explain and predict physical phenomena.

In all these thinking processes, students make use of their previous ideas and experiences. When previous ideas do not work, students try new ones, proposed by them or by teacher. New knowledge is the result of *sense making* of new experiences. In order that this sense-making process comes out as a successful one, students should experience, and be conscious of, a "conceptual change" (Dykstra et al., 1992; Galili, 1996).

Examples of physics courses that promote active learning

There is a lot of physics-course designs that, in general terms, promote active learning, although might differ in details.

Priscilla Laws (Dickinson College) designed the first lecture-free physics course, called "Workshop physics", in which students learn physics by doing physics (Laws, 1991, 1996, 1997). Students in the classroom, with the help of computers, take data about phenomena and make sense of them. Halliday & Resnick textbook is used as a resource material to find out needed information. Its content is not lecture-based delivered to the students in the classroom.

Eric Mazur (Harvard University) designed a method of active learning in which "students teach students" (Mazur, 1997). This is done through peer discussions of subtle points they did not understand by reading assignments (which replace delivery of content). Mazur only "teaches" those parts of the content which students did not comprehend by themselves.

Examples of some other courses that have accepted and implemented fully the paradigm of active physics learning are:

Student-Centered Active Learning Environment for University Physics or SCALE-UP, authored by Robert Beichner at the North Caroline State University (Beichner, 1999);

Technology-Enhanced Active Lerning or TEAL, designed by John Belcher at MIT (Dori & Belcher, 2005), and

Investigative Science Learning Environment or ISLE, developed by Eugenia Etkina and Alan van Huevelen at the Rutgers (Etkina & Van Heuvelen, 2007).

The first two courses were inspired greatly by the ground – breaking "physics studio" approach, designed and installed by Jack M. Wilson at the Rensselaer Polytechnic Institute (Wilson, 1994).

Predict — Observe — Explain: an active learning sequence

The most popular sequence of active learning is Predict — Observe — Explain. Explanation and prediction tasks were used long time ago by Piaget as diagnostic tools in his interview-based research on children's causal thinking (Piaget, 1930).

Nevertheless, the sequence was introduced into science teaching by White and Gunstone under acronym POE (Predict — Observe — Explain) (White & Gunstone, 1992), without mentioning Piaget.

In order that this sequence works, it is necessary that students first have (according to their criterions) a meaningful situation about which they can answer questions. In answering such questions, students activate their intuitive ideas about how material world works or should work.

As can be concluded from its name, the Predict-Observe-Explain sequence consists of three steps.

1. In the first step, through prediction task about how a physical phenomenon or its simple modification will work, student personally activates and formulates his or her alternative ideas about considered physical phenomenon: What do I expect that will happen? Why do I expect that this must or might happen?

   In this way, any student has an opportunity to predict personally an outcome of a simple experiment and to conceptually justifies his or her prediction. In this step, especially during elaboration of prediction justification, alternative ideas about functioning of particular segments of physical world are activated and explicitly formulated.

   When personal predictions and justifications are formulated, then group discussion of those predictions and justifications comes, with the aim to reach consensus, meaning a group prediction and justification. It is important to tell students that everyone should keep personal prediction and justification, if not completely satisfied with different prediction and justification.
2. The second step is observation and comparison between personal and group prediction and observation. In the case of well thought learning situation, the

prediction and observation do not coincide. When this happens, an “epistemological disequilibrium” has been produced and the students have concluded that their thinking about the studied phenomenon (or some of its modifications) is not adequate.

3. In the third step, students have a challenging task to explain the noted differences and to propose a change in the suppositions and reasoning their prediction was based on. The objective of the change is that the new prediction fits the observation.

My first illustration of Predict-Observe-Explain sequence implementation is students’ consideration of the behavior of a jet that flows out of a plastic bottle through a hole made in its wall (Corona et al., 2006). Students are able to predict that the jet will stop to flow out if the bottle is in free fall, but the prediction schemes are not related to the weightlessness of water but to the same speed of the bottle and the water or to the (“increased”) air pressure which keeps water in the bottle.

Nevertheless, even after the students saw that the jet stopped flowing out when the bottle was in free-fall, they do not expect that the jet will stop flow when the bottle is launched up. Their prediction, for the situation when the bottle is moving freely up, is that the jet will not stop flowing out but that the flow will be faster.

After seeing that their prediction does not fit the observation (the jet stops flow out also when the bottle is moving freely up), the students are ready to reconsider critically their situation model and explanatory schemes and to change them.

In my second illustration of the POE, students are asked to predict what will happen with a Pepsi-light can, that floats in water (Figure 3), if oil is poured in the jar.

Figure 3: A Pepsi-light can floats in water

Figure 4: A Pepsi-light can levitates in water and oil

Many students believe that the floating can, having oil pressing down, should go deeper in water. Some even predict that the can will be below the water surface. Observation is quite different: the can rises higher (Figure 4), previously under the surface “Pepsi red-white-blue heart” goes out of water. That consequence of oil pouring is almost a miracle for students. The construction of an adequate qualitative explanation is not an easy task. All students know to recite Pascal principle but fail to activate it and apply it this context. Hydrostatic oil pressure on the water surface is bigger than on the upper surface of the can and the pressure is transmitted through the water increasing the pressure on the bottom of the can.

Recently an interesting variation of POE learning sequence was suggested (Bonello & Scaife, 2009). Its acronym PEOR stays for Predict — Explain — Observe — React. The most important part of is naturally R-phase in which students can reinforce, revisit o rethink their initial ideas or test, change or reinforce new ideas.

FAST AND SLOW THINKING: A BROADER VIEW ON STUDENTS THINKING IN PHYSICS LEARNING

As students frequently "fail" in their predictions, it is useful to stress to them the importance of being able to formulate and know own ideas, even if they initially look out as unproductive. In fact, it seems that humans' thought production is carried out by two very different systems. Kahneman, Nobel Prize winner for economics, in his best-selling book *"Thinking, fast and slow"* (Kahneman, 2011), describes (and gives research-based evidence of) facets of two different modes in which human brains operate when answering questions and solving challenging problems:

System 1 is fast, automatic, frequent, emotional, stereotypic and subconscious.

System 2 is slow, effortful, infrequent, logical, calculating and conscious.

Sparing their mental energy, humans routinely use *System 1* for level of thinking needed by common-type actions (driving a car or buying groceries). Students do the same in their first try to answer "easy" school questions (which body, heavy or light one, will fall faster towards the ground?).

A common person calls *System 2* into action only when *System 1* recognizes that a problem can't be solved in stereotypical approach.

Active physics learning is a great opportunity for students to learn about normality of *System 1* activation and to start to use *System 2* more frequently. That is not an easy task and we should be very patient with students, because even scientists are not always able to resist the "siren's song" of the *System 1*.

Namely, in essence, modern training of future scientists is (or should be!) their systematic preparation in using *System 2* routinely. Nevertheless, to assure a desired accuracy level of scientific production, many quality control mechanisms are in place in scientific journals, being thought out as a collective protective bell against writings in which scientists' thinking, in some "weak moments", was too fast and carried out by the *System 1*. After years of practice, many scientists are able to use almost exclusively the *System 2* in preparing their research publications.

Surprisingly, some of them, when writing physics textbooks, especially when inventing end-of-chapter problems, give chance and voice to their *System 1* and make errors they would hardly be allowed to have in a published journal article. Alarming enough, some rather trivial errors, measured by professional standards, are repeated in various editions of the same textbooks (Slisko, 2011) and some others lived in various physics textbooks for centuries (Slisko, 2010).

A very instructive example of fast thinking universality is common answer which many today's students (and some teachers) give to very old "snail problem". Here it comes in its easy, round-number version:

A snail, driven by an unknown reason, decided to climb a 10-meter wall. During the day, it climbs 3 meters, but during the night it falls back 2 meters. After how many days and nights, will it reach the top of the wall?

a) 10 days and 10 nights;

b) 10 days and 9 nights;

c) 8 days and 7 nights;

d) 4 days and 1 night.

Well known wrong answer “10 days and 10 nights” is obtained by an “obvious” reasoning: During one day and one night the snail climbs 1 meter. If it should climb 10 meters, the needed climbing time “must be” 10 times bigger. Slow thinking gives another result. During seven days and seven nights the snail climbs seven meters. At the end of the eighth day, after climbing missing three meters, the snail will reach the top.

What is not so widely known (but surely should be!) is that the fast-thinking students’ answer was “professional answer” given by mathematicians to different formulations of this problem during a few centuries, for example, in Italy from early 13th century to late 15th century (Singmaster, 2004). Among those mathematicians was also Fibonacci, one of the best in the Middle Ages. In his famous textbook “Liber abaci”, published in 1202, he formulated the problem this way:

“On the Lion Who Was in a Pit

A certain lion is in a certain pit, the depth of which is 50 palms, and he ascends daily 1/7 of a palm, and descends 1/9. It is sought in how many days will he leave the pit.” (Sigler, 2003: p. 273)

Using the same fast-thinking approach as today’s students, Fibonacci finds the difference between 1/7 and 1/9, obtaining 2/63. After that he divides 50 with 2/63 to get the answer of 1.575 days. Nevertheless, slow-thinking answer is 1.572 days and 1.571 nights.

I will add one more example of fast-thinking phenomenon connected with the snail problem, taken from a recent published book “Games and mathematics. Subtle connections” (Wells, 2012), written by David Wells, former Cambridge student, chess champion and prolific author of many popularization books on mathematics. The book, issued by one of the world best publishing company, has the following review:

“Wells notes that mathematicians use analogy and other play techniques as they construct proof. He draws the reader to a new appreciation of proof — not mere certification of correctness but a deeper exploration of the mathematical world. Games and Mathematics makes an important advance in communicating the nature of mathematics. It contains a profound message for philosophers of mathematics, but all mathematically-inclined readers will find Games and Mathematics as compelling as Wells’ excellent ‘Curious and Interesting’ books.”

Dr. Paul Brown, Carmel School, Perth, Western Australia and Author of
“Proof: Interesting Activities in Conjecture and Mathematical Proof”

After such a review, nobody would expect that Wells would offer an incorrect, fast-thinking answer to his formulation of the snail problem (p. 4):

“Another traditional puzzle appeals to me because it sets the solver a trap, albeit a rather obvious one. Here is one version. A snail — or a serpent or a frog! — lies at the bottom of a well, 30 units deep. It climbs 6 units every day but falls back 3 units every night. How long does it take to escape from the well? The obvious answer is that the snail rises 3 units every day-and-night, on balance, so it takes 10 days-and-nights to escape, but this is wrong because it will actually reach the top of the well half-way through the 10^{th} day and after only 9 nights.”

Slow-thinking answer is different. During eight days and eight nights, the snail would climb up to 24 units and during the ninth day, after climbing missing 6 units, would reach the top.

THE ESSENCE OF ACTIVE LEARNING: SELF-REGULATED LEARNING HOW TO LEARN

As the snail problem shows, fast thinking is very hard to be freed off. Mind, as many of us, first wants to try to carry out mental tasks in the most effortless way. It seems to me that the road toward slow thinking can be better walked if we help students learn how authentic human learning works. In order to make successful experiments with their own learning to improve it, only practice of active learning is not enough. They should also learn about its theory.

Active physics learning, as actually designed and practiced in physics education, might be improved, both at students' and teachers' side, if it is informed about a more complex and much elaborated educational construct, called *"self-regulated learning"* (Pintrich, 1995; Low & Jin, 2012; Zimmerman & Schunk, 2013).

So, a very challenging and far-reaching approach to design of active physics learning would be to inform students much more about the complexity of the learning and thinking process, fast and slow thinking are only a top of an iceberg. That would be done best, if we design opportunities for the students to plan, practice and observe their own learning within the self-regulation paradigm.

Regarding metacognitive aspects of learning, self-regulated learners plan, set goals, organize, self-monitor, and self-evaluate gained results at various points during the learning process. They are also very motivated, showing high self-efficacy, self-attribution and intrinsic task interest. In addition, self-regulated learners know and accept that learning results are better with more efforts and persistence and inside of an adequate learning environment (Zimmerman, 1990). The success of self-regulated learning depends of students' abilities to activate and use in the best way metacognitive, motivational and behavioral resources and strategies.

According to Zimmerman (2002), self-regulated learning process consists of three different phases:

- Forethought or planning phase;
- Performance phase; and
- Self-reflection phase.

In the Planning phase, students activate all necessary knowledge and skills to understand the given problem and make a plan how to solve it.

In the Performance phase, they monitor how they perform, whether some unexpected or unclear details appear, and verify validity of partial and final solution.

Self-reflection phase is the most important part of self-regulated learning. In it, students are supposed to look back and evaluate critically their performance and what was learned and what was not. In the last phase, they try to determine what possible causes of their unsuccessful learning might be. In order to assist students in their self-reflective performance, we should provide students with an adequate and timely feedback at every stage of implemented learning sequence.

In addition, formative and summative assessment should award personal ideas and arguments not only for correctness but also for clearness or originality. Students appreciate when we are interested in what and how they think and when their initial thinking is not punished or subject of laugh. Freedom of thinking, which includes an explicit right to err, is the first precondition of any learning.

Learning from self-recognized and self-corrected personal and group errors seems to be a better way to construct knowledge and skills than direct instruction (Kapur, 2012; Siler et al., 2013).

WHAT ARE SOME EFFECTS OF ACTIVE PHYSICS LEARNING?

In his doctoral research, Dr Mirko Marušić, then a high-school physics teacher in Split (Croatia), explored, under my mentorship, different effects of two designs of active learning experiences: *Read – Present – Question (RPQ)* and *Experiment – Discuss (ED).* The topics of the RPQ group were actual CERN experiments. The topics of the ED group were simple phenomena for which students hold strong intuitive ideas which differ from scientific ones.

The research was carried out during one semester (16 weeks), within one 45-minute session per week. Interested readers can find more details about students, curriculum and treated themes, in the articles cited below.

In brief, the ED group outperformed the RPQ group in

Classroom Test on Scientific Reasoning (Marusic & Slisko, 2012a);

Colorado Learning Attitude about Science Survey (Marusic & Slisko, 2012b);

Changing negative attitude towards attractiveness of school physics (Marusic & Slisko, 2012c); and

Changing negative attitude towards physics as profession (Marusic & Slisko, 2012d).

Although the analysis is still under way, preliminary results indicate that students initially believed that physics learning helps in developing logical thinking but not creative thinking. After active learning experiences, the students in ED group made much bigger attitudinal change towards the relationship between physics learning and creative thinking. The change in concrete thinkers' attitude is very characteristic. In the RPQ group, concrete thinkers after learning experiences with modern physics topics believe less that physics learning has something to do with development of creative thinking. In ED group the situation is quite opposite. Concrete thinkers made bigger relative attitudinal improvement regarding creativity development.

To measure that attitude and its change, students had to express their justified opinions regarding the statement:

"I feel good while learning physics because it helps me to develop my creative thinking."

The students could choose one option on a 5-point Likert scale:

(a) I strongly disagree (graded as "-2"); (b) I disagree ("-1"); (c) Neutral ("0"); (d) I agree ("+1"); and (e) I strongly agree ("+2").

Only in ED group, there were cases of total attitudinal change. Below come three of them:

STUDENT 1

Pre: (-2) *I don't feel well in physics classes because it is boring. This also means there is no creativity, no creative thinking.*

Post: (+2) *I feel good in physics classes that look like a game. It makes it always exciting and encourages us to think creatively with no fear of bad grades.*

STUDENT 2

Pre: (-2) *Studying physics may develop logical but definitely not creative thinking. Everything is predefined. I can fantasize about "what if" but that is not physics.*

Post: (+2) *Creativity is very much present in physics. It was nice to experience that creative thinking is possible in physics classes as well (debate, analyzing everyday life examples, interesting experiments...).*

STUDENT 3

Pre: (−2) *Creativity in physics that I know does not exist. It may be present in physics in general but I don't find it in physics as a school subject.*

Post: (+2) *Creative thinking processes in physics classes surprise me. We were asked to explain the experiments in from of the class. It was creative and even interesting (funny at times). It is a great feeling!*

HOW TO PROMOTE STUDENTS' CREATIVITY IN ACTIVE PHYSICS LEARNING?

In the above-commented pilot research, we did not explore students' personal definitions of creativity, believing that a common-sense notion of creativity (generation of novel and useful ideas and products) is shared by majority of them.

In addition, our hypothesis was that active physics learning would help students to discover and feel their own creative potentials.

In the group that performed and discussed experiments with easy-to-find ordinary objects that happened much more than in the group in which students were reading and presenting information about sophisticated physics experiments carried out at the CERN. This is an important initial result which shows that active physics learning can contribute to improve attitude students have towards the relationship between physics learning and development of creative thinking. Students are more likely to connect creativity and physics learning when they do physics, no matter how simply is to carry out and modify physical phenomena studied, than when they read about physicists do cutting-edge physics with extremely sophisticated technology.

Now, more than ever before, it is clear to many that creativity can't be only nice-looking decorative element among other educational objectives. Everybody agree that today's and tomorrow's economic, social, nutritional and medical problems of modern world can only be solved by ever-increasing personal and collective creative thinking. Such a cultural change would be impossible if "teaching and learning creativity" isn't present in classroom on daily basis.

Nevertheless, such a task is far from being simple because there are many hard implementation questions. For teachers, the most important are:

a) How to have real and adequate presence of creativity in curriculum?

b) How to teach creativity in effective ways?

c) How to evaluate progress in creativity thinking of students?

Due to the fact that psychological processes, which creativity thinking and behavior are based on, are extremely difficult to define, explore and evaluate (Runco, 2004; Hennessey & Amabile, 2010), these important questions have by now only initial answers (Piirto, 2011; Gregerson et al., 2013; Barbot et al., 2011). In addition, some "practical" suggestion for classroom building of students' creativity are either too numerous (Cheng, 2004) or too general (Gregory et al., 2013).

CREATIVITY IN PROBLEM SOLVING

In my own teaching, at the very beginning, I define creativity operationally as non-routine thinking. To give meaning to this "negative" definition of creativity, students have first to experience what routine thinking is and what its limitations are.

The best way to show it is to present good puzzles to students. Their usefulness comes from the fact that they are easily understandable and usually do not require specific-content knowledge for their solution.

When students approach a puzzle within routine, fast thinking, they either get wrong answer or conclude that it is impossible to answer it. An acceptable answer, of course, can be found only by using non-routine thinking. That is an "Eureka moment" for many students. It comes as an award for initial common-felt frustration when they were in routine-thinking phase.

According to many authors, multiple experiences with transitions between routine and non-routine thinking, when followed by related epistemological discussions and reflections, help students in "improving thinking, learning and creativity" (Bransford & Stein, 1993), learning about "the art and logic of breakthrough thinking" (Perkins, 2000) and making progress in "critical thinking, mathematics, and problem solving" (Michalewicz & Michalewicz, 2008).

Connecting creativity and non-routine thinking give me opportunity to help students discover that they are much more creative than they usually think. Namely, many of them connect creativity only with big artistic and scientific creations. In addition, they discover that they can improve such-defined creativity. That is best practiced with the problems that can be solved in routine (algorithmic) ways, but whose solution is much simpler or interesting by using non-routine (creative) approach. Asking for and praising alternative solutions of problems, in my view, give students an opportunity to build disposition for and to practice creative thinking.

When students acquire sufficient content knowledge, then they can explore and improve their creative potential solving "physics puzzles". These are calculation or practical physics problems that, at first sight, look impossible to solve:

Is it possible to determine mean density of Earth using a satellite and a chronometer?

Is it possible to determine relative density of oil using a plastic tube and a ruler?

Is it possible to determine the depth of a lake using only graduated test tube?

As in the case of ordinary puzzles, routine thinking (to determine density one needs to measure mass and volume) is an obstacle for finding the solution. Non-routine or creative thinking is necessary in order to find out surprising fact that there exists a relationship between mean Earth density and the period of a satellite, with no other physical quantity involved. That makes possible to calculate mean density when the value of the period is measure by a chronometer.

LIFTING TWO GLASSES BY ONE BALLOON: AN EXAMPLE OF STUDENTS' PEDAGOGICAL CREATIVITY

Physics students at my University are exposed mainly to the traditional lecture-based teaching. So, it is not a wonder that, in their first try to prepare and present potential engaging demonstrations for middle-school pupils, the students think that the most important part of them is a "clear and logical" explanation of the physics behind demonstrations. Because of such a belief, in the course "Physics teaching" (an obligatory methodic course for all physics students!), I have to help students' develop “pedagogical creativity”: an ability to use in novel and appropriate way known physics demonstrations. “Appropriate way” means that presentation of a demonstration should be designed in the form that is likely to motivate and engage pupils in active physics learning.

In the course offered in Spring of 2005, the student Sergio Rivera Hernández designed the best sequence. The account which follows is revised version of the presentation which Sergio and I presented the same year at the International Workshop “New Trends in Physics Teaching” (Rivera Hernández & Slisko, 2005).

Sergio started his demonstration by putting on the table a glass (in vertical position) and a desinflated balloon. The he asked: Is it possible to lift the glass using the ballon?

After a while, other students figured out a right answer. The ballon is put in the glass and inflated. When the balloon presses the wall of the glass strongly enough, it is possible to lift the glass by lifting the neck of the balloon. (Figure 5).

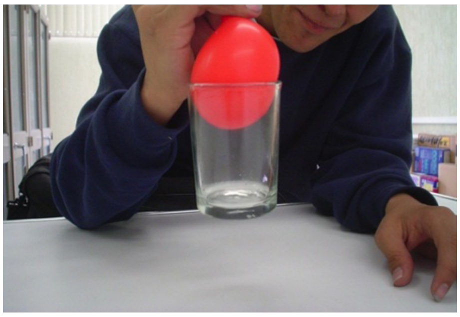


Figure 5: Lifting one glass by the balloon

Figure 6: Lifting two glasses by the balloon

After that, a serious challenge came. Sergio put on the table two glasses in vertical position and asked: Is it possible to lift these two glasses using one balloon?

In the first moment, it was a real puzzle for all and nobody had an idea how to lift two glasses. After some time, there were a few unsuccessful tries. A student wanted to use routine solution. She tried to force one glass into other in order in order to lift them together. She pressed so strongly and broke one glass. Finally, we all had to admit that we were totally clueless.

Sergio took two glasses and put them in horizontal position, with their openings near one to other. The he put the ballon between the glasses and inflated it. It was possible to lift two glasses (Figure 6). We all were delighted with the solution which appears to be a simple one when one sees it, but it is extremely hard to find if one follows routine thinking.

After some other students repeated to solution themselves, they had task to discuss the physical mechanism responsible for glass lifting. Students came with two causal models. In the “friction model”, the friction force between the inflated balloon and the glass wall doesn’t allow separation of the glass and the ballon. In the “pressure difference model”, the separation of the glass and the balloon was not possible because of reduced pressure of the air in the glass. That was an *ad hoc* “theory” because students didn’t have any idea what caused that reduced pressure.

The next task was to design experimental tests of two proposed causal mecanisms. One proposal was the following:

If the lifting is due to friction force, it will not work if the friction is reduced drastically.

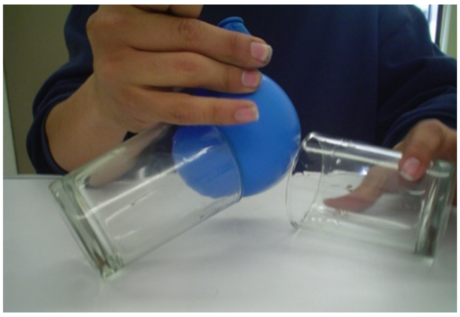


Figure 7: The oiled glass couldn't be lifted

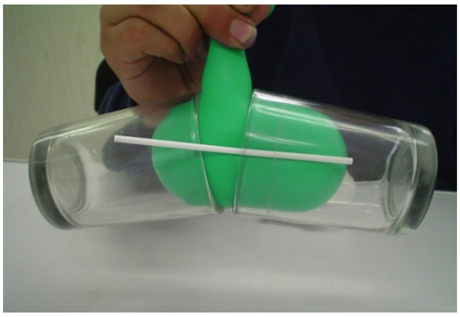


Figure 8: Equalizing pressure does not make change

To check it, students oiled one glass. The result was that the balloon could lift un-oiled glass but not the oiled one (Figure 7). This experiment confirmed predictive power of "friction model".

Students argued that if the cause of lifting is the reduced pressure in the glass, then if the pressure in the glass is made equal to the atmospheric pressure, the glass wouldn't be lifted. That prediction was checked in the following way. A strong plastic straw was placed between the glass and the balloon, connecting the air in the glass with air outside. That made both pressures equal, without destroying "lifting power" of the balloon (Figure 8). This experiment reduced the credibility of the "pressure difference model".

I consider that both purposeful preparation of engaging demonstrations and discussion and design of experiments, that are necessary to understand better the physics which make demonstrations possible, are adequate and act in complementary fashion to promote students' pedagogical and scientific-thinking creativity.

Weightlessness in classroom: another opportunity for students' creativity

In the course "Physics teaching" students freely choose which demonstration might be engaging for middle-school pupils. They have another opportunity for showing their pedagogical creativity. It happens after they learn about "Bottle in free-fall" demonstration of weightlessness. After getting a clear idea why it happens, as a transfer test, they should design a different free-fall demonstration of weightlessness. I will present a few of students' proposal.

The first is "magnetic demonstration", whose initial idea was proposed by the student Heladio Ayala. Two neodymium magnets (Figure 9) are placed in the plastic tube, one fixed on the top and other movable on the bottom. When the tube is at rest, the upper magnet is unable to lift the lower magnet. In free-fall, the lower magnet is attracted upwards (Ayala et al., 2011).

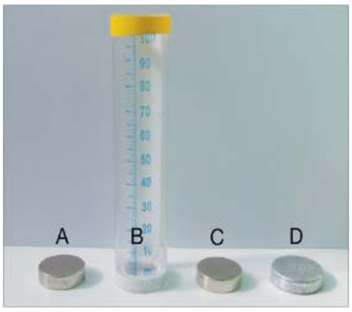


Figure 9: Items needed for magnetic

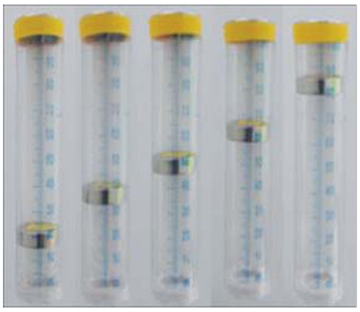


Figure 10: The lower magnet is attracted upwards. Demonstration of weightlessness

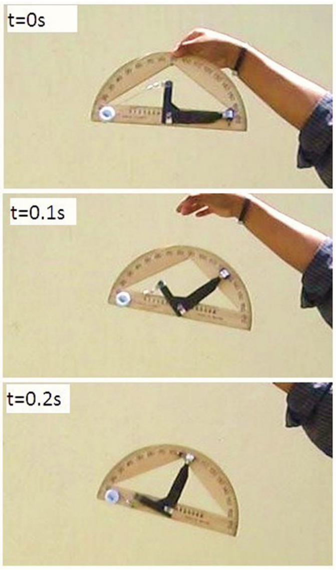


Figure 11: Demonstration with a protractor

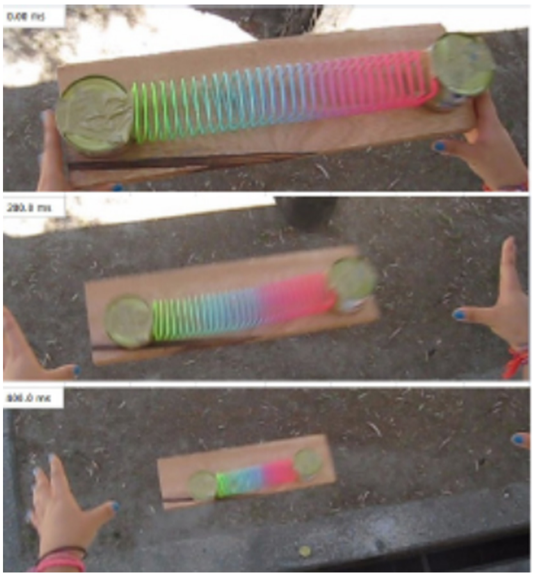


Figure 12: Demonstration with a slinky and two cans

The student Eric F. Jiménez Andrade proposed a demonstration with a protractor, a hard cardboard in the form of an L, a spring and a weight. When the protractor is at rest, the weight and the spring keeps the longer arm of the cardboard in horizontal position. In free-fall, the cardboard starts to rotate, because the weight becomes weightless (Figure 11).

The students Adriana Pérez Martínez and Raúl Felipe Maldonado Sánchez proposed a demonstration with a slinky, wood board and two cans. Two cans are attached to the extended slinky and placed on the board.

When in rest, the friction between the cans and the board prevents the slinky from contracting.

In free fall, the cans don't press the board, the friction disappears and the slinky contracts (Figure 12).

Not all proposals were successful. For example, some students thought that a bubble in free-falling bottle should be motionless, because the buoyant force would disappear. They based their design of a weightlessness demonstration on the slow-thinking idea *"no force – no motion"*.

Video recording with high-speed camera and a frame-after-frame analysis, performed by Adrian Corona, show that the bubble continues to move up even after the buoyant force was switched-off in free-fall (Figure 13).

Figure 13: The bubble continues to move upwards even in the free-fall

CONCLUSIONS

According to my experience, active physics learning is able to accelerate students' cognitive growth, make positive changes in students' attitude towards physics and to improve their conceptual understanding and creative thinking. I am always glad to learn students' unexpected and amazing ideas. In addition, it makes me happy when students' enjoy learning and when they reveal anonimously that they share the joy or learning with parents, brothers, boyfriends and girlfriends.

To further develop active physics learning, we should work more exlicitly on informing students about all complexity of human learning. The paradigm of self-regulated learning has a lot results which might be useful for designing improved active learning sequences.

On the other side, active physics learning should not be preferent pedagogical approach in only one or a few courses. It should be rather a basic element of institutional policy in the domain of learning and teaching. Such an institutional acceptance is neither fast nor easy, due to many "obvious" counter arguments. Seemingly the most solid, cost-effectiveness of lecture-based teaching, was proven to be false (Wilson, 1994). Changes made in Prof. Lewin's video course in its edX version, by which some elements of explicit students' mental activities in video watchings were introduced, are certainly a very good news (Belcher, 2013). Let's hope that in the future we will lecture less and students will lear more.

ACKNOWLEDGEMENT

This article is partially based on the results of Josip Slisko's sabbatical research project *"Active physics learning on line"* supported by CONACyT Mexico in the period August 2012–July 2013.

The author would like to thank Dr. Marina Milner-Bolotin, from the University of British Columbia, Vancouver, for her insightful comments and suggestions.

REFERENCES

Argyris, C. (1991). Teaching smart people how to learn. *Harvard Business Review*, 4(2), 99–109.

Ayala, H., Slisko, J. & Corona, A. (2011). Magnetic demonstration of weightlessness: A spark of student creativity. *The Physics Teacher*, 49 (8), 524–525.

Barbot, B., Besançon, M. & Lubart, T. I. (2011). Assessing Creativity in the Classroom. In *The Open Education Journal 4, Supplement 1: M5*, 58–66.

Beichner, R. J. (1999, unpublished). *Student-Centered Activities for Large-Enrollment University Physics (SCALE UP).* Lecture presented at the Sigma Xi Forum: Reshaping Undergraduate Science and Engineering Education: Tools for Better Learning, Minneapolis.

Belcher, J. (2013). MIT Physics Department's experience with edX. *MIT Faculty Newsletter*, 26(1), 12–14.

Bonello, C. & Scaife, J. (2009). PEOR: Engaging students in demonstrations. *Journal of Science and Mathematics Education in Southeast Asia*, 32(1), 62–84.

Bonwell, C. C. & Eison, J. A. (1991). *Active learning. Creating excitement in the classroom.* Washington: The George Washington University.

Bransford, J. D., Brown, A. L. & Cocking, R. R. (Eds.). (2001). *How people learn. Brain, mind, experience, and school. Expanded edition.* Washington, D.C.: National Academy Press.

Bransford, J. D. & Stein, B. S. (1993). *The ideal problem solver. A guide for improving thinking, learning and creativity.* New York: W. H. Freeman & Company.

Cheng, V. M. (2004). Developing physics learning activities for fostering student creativity in Hong Kong context. *Asia-Pasific Forum on Science Learning and Teaching*, 5 (2), 1–33.

Corona, A., Sliško, J. & Planinsic, G. (2006). Rising freely bottle also demonstrates weightlessness. *Physics Education*, 41(3), 8–9.

Deslauriers, L., Schelew, E. & Wieman, C. (2011). Improved Learning in a Large-Enrollment Physics Class. *Science*, 332(6031), 862–864.

Dori, Y. J. & Belcher, J. (2005). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *The Journal of the Learning Sciences*, 14(2), 243–279.

Drucker, P. F. (1999). Knowledge-worker productivity: The biggest challenge. *California Management Review*, 41(2), 79–94.

Drucker, P. F. (2005). Managing Oneself. *Harvard Business Review*, 83(1), 100–109.

Dykstra, D. I., Boyle, C. F. & Monarch, I. A. (1992). Studying conceptual change in learning physics. *Science Education*, 76(6), 615–652.

Etkina, E. & Van Heuvelen, A. (2007). Investigative science learning environment — A science process approach to learning physics. In Redish, E. F., Cooney, P. J. (Eds.), *Research-based reform of university physics.* College Park, MD: American Association of Physics Teachers.

Galili, I. (1995). Interpretation of students' understanding of the concept of weightlessness. *Research in Science Education*, 25(1), 51–74.

Galili, I. (1996). Students' conceptual change in geometrical optics.*International Journal of Science Education*, 18(7), 847–868.

Galili, I. (2001). Weight versus gravitational force: Historical and educational perspectives. *International Journal of Science Education*, 23(10), 1073–1093.

Gautreau, R. & Novemsky, L. (1997). Concepts first — a small group approach to physics learning. *American Journal of Physics*, 65(5), 418–428.

Graham, P. A. (Ed.). (2002). *Knowledge Economy and Postsecondary Education: Report of a Workshop.* Washington, DC: National Academic Press.

Gregerson, M. B., Snyder, H. T. & Kaufman, J. C. (2013). *Teaching Creatively and Teaching Creativity.* New York: Springer.

Gregory, E., Hardiman, M., Yarmolinskaya, J., Rinne, L. & Limb, C. (2013). Building creative thinking in the classroom: From research to practice. *International Journal of Educational Research*, 62, 43–50.

Gürel, Z. & Acar, H. (2003). Research into students' views about basic physics principles in a weightless environment. *Astronomy Education Review*, 2(1), 65–81.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74.

Harmin, M. (1994). *Inspiring active learning. A handbook for teachers.* Alexandria: Association for Supervion and Curriculum Development.

Hennessey, B. A. & Amabile, T. M. (2010). Creativity. *Annual Review of Psychology*, 61, 569–598.

Hoellwarth, C., Moelter, M. J. & Knight, R. D. (2005). A direct comparison of conceptual learning and problem solving ability in traditional and studio style classrooms. *American Journal of Physics*, 73(5), 459–463.

Jarvis, P. (Ed.). (2001). *The Age of Learning: Education and the Knowledge Society.* London: Taylor and Francis Group.

Kahneman, D. (2011). *Thinking, fast and slow.* New York: Farrar, Straus and Giroux.

Kapur, M. (2012). Productive failure in learning the concept of variance. Instructional *Science*, 40(4), 651–672.

Keeling, R. P. & Hersh, R. H. (2012). *We're Losing Our Minds. Rethinking American Higher Education.* New York: Palgrave Macmillan.

Lewin, W. (2012). *For the Love of Physics: From the end of the rainbow to the edge of time — a journey through the wonders of physics.* New York: Simon and Schuster.

Lewin, W. (1999). *Lecture 7.* Available at http://ocw.mit.edu/courses/physics/8-01-physics-i-classical-mechanics-fall-1999/video-lectures/lecture-7/

Laws, P. (1991). Workshop Physics: Learning introductory physics by doing it. *Change: The Magazine of Higher Learning*, 23(4), 20–27.

Laws, P. W. (1996). *Workshop Physics Activity Guide Modules 1–4*, New York: John Wiley and Sons.

Laws, P. W. (1997). Millikan Lecture 1996: Promoting active learning based on physics education research in introductory physics courses. *American Journal of Physics*, 65(1), 14–21.

Low, R. & Jin, P. (2012). Self-regulated learning. In *Encyclopedia of the Sciences of Learning* (3015–3018). New York: Springer.

Marusic, M. & Slisko, J. (2012a). Influence of three different methods of teaching physics on the gain in students' development of reasoning. *International Journal of Science Education*, 34(2), 301–326.

Marusic, M. & Slisko, J. (2012b). Effects of two different types of physics learning on the results of CLASS test. *Physical Review Special Topics: Physics Education Research*, 8(1), 010107.

Marusic, M. & Slisko, J. (2012c). Increasing the attractiveness of school physics: The effects of two different designs of physics learning. *Revista Mexicana de Física E*, 58(1), 75–83.

Marusic, M. & Slisko, J. (2012d). Many high-school students don't want to study physics: active learning experiences can change this negative attitude! *Revista Brasileira de Ensino de Física*, 34(3), 3401.

Mazur, E. (1997). *Peer Instruction: A User's Manual.* New Jersey: Prentice Hall.

McDermott, L. C. (1991). Millikan Lecture 1990: What we teach and what is learned — Closing the gap. *American Journal of Physics*, 59(4), 301–315.

McDermott, L. C. (1993). Guest Comment: How we teach and how students learn — A mismatch? *American Journal of Physics*, 61(4), 295–298.

Meltzer, D. E. & Thornton, R. K. (2012). Resource letter ALIP-1: Active-learning instruction in physics. *American Journal of Physics*, 80(6), 478–496.

Michalewicz, Z. & Michalewicz, M. (2008). *Puzzle-based learning: Introduction to critical thinking, mathematics, and problem solving.* Melbourne: Hybrid Publishers.

Perkins, D. (2000). *Archimedes' bathtub. The art and logic of breakthrough thinking.* New York: W. W. Norton & Company.

Piaget, J. (1930). *The child's conception of physical causality.* Oxford: Harcourt, Brace & Company.

Piirto, J. (2011). *Creativity for 21st century skills. How to embed creativity into the curriculum.* Rotterdam: Sense Publishers.

Pintrich, P. R. (1995). Understanding self-regulated learning. *New directions for teaching and learning*, 63, 3–12.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223–231.

Rivera Hernández, S. & Slisko, J. (2005). *Levantar dos vasos mediante un globo: usando un truco de fiestas para enseñar y aprender la naturaleza de la física. Memorías del taller internacional "Nuevas Tendencias en la Enseñanza de la Física".* Puebla: Facultad de Ciencias Físico-Matemáticas.

Runco, M. A. (2004). Creativity. *Annual Review of Psychology*, 55, 657–687.

Scott, T., Gray, A. & Yates, P. (2013). A controlled comparison of teaching methods in first-year university physics. *Journal of the Royal Society of New Zealand*, 43(2), 88–99.

Sharma, M. D., Millar, R. M., Smith, A. & Sefton, I. M. (2004). Students' understandings of gravity in an orbiting space-ship. *Research in Science Education*, 34(3), 267–289.

Sigler, L. E. (2003). *Fibonacci's Liber Abaci. Leonardo Pisano's Book of Calculation. First soft edition.* New York: Springer.

Siler, S. A., Klahr, D. & Price, N. (2013). Investigating the mechanisms of learning from a constrained preparation for future learning activity. *Instructional Science*, 41(1), 191–216.

Singmaster, D. (2004). *Sources in recreational mathematics. An annotated bibliography. Eight preliminary edition.* Available at http://puzzlemuseum.com/singma/singma6/SOURCES/singma-sources-edn8-2004-03-19.htm#Toc69534276

Slisko, J. (2010). "Total force" on bodies immersed in air and water: An error living three centuries in physics textbooks. *Review of Science, Mathematics and ICT Education*, 4(1), 5–23.

Slisko, J. (2011). Repeated errors in physics textbooks: What do they say about the culture of teaching? In Raine, D., Hurkett, C. & Rogers, L. (Eds.), *Physics Community and Cooperation. Vol. 2, Proceedings of the GIREP-EPEC & PHEC 2009 International Conference*, Leicester: Lulu / The Center for Interdisciplinary Science, University of Leicester, 31–46.

Thacker, B., Kim, E., Trefz, K. & Lea, S. M. (1994). Comparing problem solving performance of physics students in inquiry-based and traditional introductory physics courses. *American Journal of Physics*, 62(7), 627–633.

Tural, G., Akdeniz, A. R. & Alev, N. (2010). Effect of 5E teaching model on student teachers' understanding of weightlessness. *Journal of Science Education and Technology*, 19(5), 470–488.

Wagner, T. (2008). Rigor redefined. *Educational Leadership*, 66(2), 20–25.

Wells, D. (2012). *Games and mathematics. Subtle connections.* New York: Cambridge University Press.

Wells, M., Hestenes, D. & Swackhamer, G. (1995). A modeling method for high school physics instruction. *American Journal of Physics*, 63(7), 606–619.

White, R. & Gunstone, R. (1992). *Probing Understanding.* London and New York: Falmer Press.

Wieman, C. & Perkins, K. (2005). Transforming physics education. *Physics Today*, 58(11), 26–41.

Wilson, J. M. (1994). The CUPLE physics studio. *The Physics Teacher*, 32(9), 518–523.

Zimmerman, B. J. (1990). Self-regulated learning and academic achievement: An overview. *Educational psychologist*, 25(1), 3–17.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into practice*, 41(2), 64–67.

Zimmerman, B. J. & Schunk, D. H. (Eds.). (2013). *Self-regulated learning and academic achievement: Theoretical perspectives.* New York: Routledge.

JOSIP SLIŠKO
Benemérita Universidad Autónoma de Puebla, Puebla, Mexico

sciED

Scientia in educatione 8(Special Issue), 2017
p. 101–118
ISSN 1804-7106

Active Learning and Teacher Training: Lesson Study and Professional Learning Communities

Kyoko Ishii

Abstract

Active learning is an innovation of teaching and learning and strongly connected to teacher education reform. A teacher's role in a knowledge-based society is being shifted from a knowledge teller to a facilitator. It is difficult to shift a teacher's perspective from "how to teach" to "how students learn." However, through a collaborative lesson study, teachers can discuss students' learning in a classroom. The university can function as a facilitator to cultivate a professional learning community.

This paper discusses the practice of active learning in teacher training at the University of Fukui in Japan. The faculty provides active learning for prospective teachers to engage collaboratively in scientific inquiry using physics by inquiry.

Based on the viewpoint that teacher development is a continuous, lifelong process, and the teacher is a reflective practitioner, teacher training should also be an active, lifelong endeavor. Moreover, the system and structure of the lesson study and collaborative reflection promote a professional learning community. Both pre-service and in-service teachers develop pedagogical content knowledge through repeated practice and reflection.

Key words: lesson study, community of practice, professional learning community, teacher training, intern, physics by inquiry.

INTRODUCTION

Recently, the academics field has focused on the challenges of active learning; for example, the theme of the International Conference on Physics Education in 2013 was “Active learning — in a changing world of new technologies”. The attention on active learning means that the interest of education has turned from “how to teach” to “how students learn”. Therefore, active learning is an innovation of teaching and learning and strongly connected to teacher education reform.

Teacher training has concentrated on how to teach and has been conducted without students in places such as a university and a lecture hall. However, it is difficult to learn how students learn in such a situation. Education reform in active learning has not been promoted, and the study has not been collaboratively connected to school practice. Therefore, the importance of collaboration and the professional learning community is discussed (Lieberman & Miller, 2008; Hargreaves, 1994), but is it clear how to cultivate and promote them?

The purpose of this paper is to clarify the strategy of active learning in teacher training. This paper therefore analyzes how the structure of active learning is brought into teacher education, particularly in Fukui Prefecture and the University of Fukui.[1] The paper investigates the active teacher development process regarding the following practical theories:

1. The “teacher as a reflective practitioner” is well known from Schön’s *The Reflective Practitioner* (1984).
2. Effective learning requires “active mental engagement”, which is noted in *Physics by Inquiry* (McDermott & Physics Education Group at the University of Washington, 1996).

The paper is organized as follows. First, it shows the purpose and background of this practice, such as the current situation of education and teacher education in Japan. Particularly, the lesson study as part of the culture of teacher training in Japan is introduced. Section 2 presents the new challenges of education in Fukui Prefecture and the University of Fukui. Section 3 demonstrates the three practices of active learning in teacher training in Fukui Prefecture and the University of Fukui. The first practice is the undergraduate course challenge using physics by inquiry (McDermott & Physics Education Group, 1996) at the University of Fukui (Ishii & Yamada, 2012). The second practice is the lesson study held in a lower secondary school in Fukui Prefecture. The third practice is the student teacher’s lesson study and the curriculum of the graduate school at the University of Fukui (Ishii, 2011; Sasaki, 2011).

According to these three practices, this paper discusses how active learning is related to teacher training through cultivating the professional learning community.

TEACHER AS A REFLECTIVE PRACTITIONER

For many years, the primary objective of teachers has been to transmit a body of knowledge to their students. Teachers want to know how to teach effectively and want to master techniques for achieving this. Workshops have provided transmitted,

---

[1] Fukui Prefecture, with a population of 803 200 and an area of 4 189 km^2, is located 320 km from Tokyo and borders Kyoto Prefecture. It has 330 schools and three education centers, including 30 professional development schools (PDS) with a strong relationship to the University of Fukui, which form the core of the distributed learning community.

non-reflective experiences. However, it is time for this to change: teaching should be transformed into a process of lifelong professional development.

A teacher's development had previously been discussed as that of a professional practitioner (Schön, 1984). According to Schön, reflective teachers try to listen to their students; they ask themselves, "What do students think in a situation like this?" or "What is causing students' confusion?" It means teacher training must be changed.

The teacher's role should change from a knowledge teller to a facilitator supporting students' collaborative learning, a manager of a community, and a reflective practitioner. The focus must be changed from "how to teach" to "how students learn" because the purpose of education is to make students understand. Teacher training must prepare the opportunities to share teachers' experiences and steer the discourse toward students' learning.

Lesson Study

The lesson study is a traditional Japanese way of training teachers through actual "lessons" at the school. Lewis described it as "a process in which teachers jointly plan, observe, analyze, and refine actual classroom lessons" (2012). It was first introduced and covered extensively in the book *The Teaching Gap* (Stigler & Hiebert, 1999). It has a long history in Japan and has become a central issue in educational practice and the professional development of teachers. There are many kinds of lesson studies, such as in-school, in the district, and at the national conference. Usually, a lesson study consists of a research lesson (open class) and debriefing, and it is conducted in a single day (National Association for the Study of Educational Methods, 2011).

Even though the lesson study originated in Japan nearly a century ago, it has spread its wings worldwide and is currently flourishing in several countries as a tool to promote the professional development of teachers. The lesson study is now growing in different ways, responding to a variety of social, cultural, and political contexts, and being applied to a range of disciplines. The World Association of Lesson Studies (WALS) was established in 2006 and has since held annual conferences to share the research and practice of the lesson study. More than 32 countries engage in lesson studies with the Japan International Cooperation Agency (JICA), Asia-Pacific Economic Cooperation (APEC), and United Nations Educational, Scientific and Cultural Organization (UNESCO) (Akita, 2012).

Traditionally, the lesson study was considered a special opportunity for teachers to open their classes and show their lessons to their colleagues and supervisors. Before opening their classes, teachers were under pressure and feared how their lessons and teaching abilities would be rated. They prepared hard to make good lessons to show their colleagues or supervisors. Traditionally, a good teacher meant a technical expert. However, in the new trend, teachers are reflective practitioners, whose aim is to conduct case studies, enabling discussion of students' learning processes. As a result, in the new lesson studies, participants do not focus on teachers' activities but rather on children's learning (Sato, 2011).

Japanese educational system — past and present

The educational system in Japan is centralized. Primary and lower secondary school (junior high school) is compulsory, and 98 % of students go to high school for three years after compulsory education. Following high school graduation, 56 % of students attend institutions of higher learning, such as university or college. A national curriculum (course of study) determines the contents of learning from primary school to high school for each grade. Textbooks authorized by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) are distributed free to all students during the compulsory education phase.

Based on the course of study, science lessons focus on developing students' problem-solving skills, scientific thinking, and capacity for in-depth understanding (MEXT, 2008). Actually, many lessons have been teacher centered with an emphasis on transmitting knowledge (Murata & Yamaguchi, 2010).

Education required in a knowledge-based society

The quality of Japanese education is shown in an international survey as Programme for International Student Assessment of Organisation for Economic Co-operation and Development (PISA-OECD) or Trends in International Mathematics and Science Study (TIMSS) (OECD, 2007). Japanese students have good scientific skills and demonstrate them well. Nonetheless, the survey reveals that they have difficulties applying their knowledge to novel situations and avoid solving unknown questions. Their science lessons have little connection to the real world. The rate of blanks on exams — in which students didn't write anything — is very high. Moreover, there appears to be a poor attitude toward studying. According to the OECD report on Japan, "Students who learn just to memorize and reproduce scientific knowledge and skills may find themselves ill-prepared for tomorrow's job market" (2007).

What does tomorrow's job market look like? What kind of innovation will be required in the future? In Japan, the industrial structure has changed in 50 years. The agricultural population is decreasing. The main professions have shifted from production of goods to designing, planning, generating ideas, publishing, marketing, advertising, distribution, and services. The workforce concentration is also changing from manufacturing products to services (Figure 1).

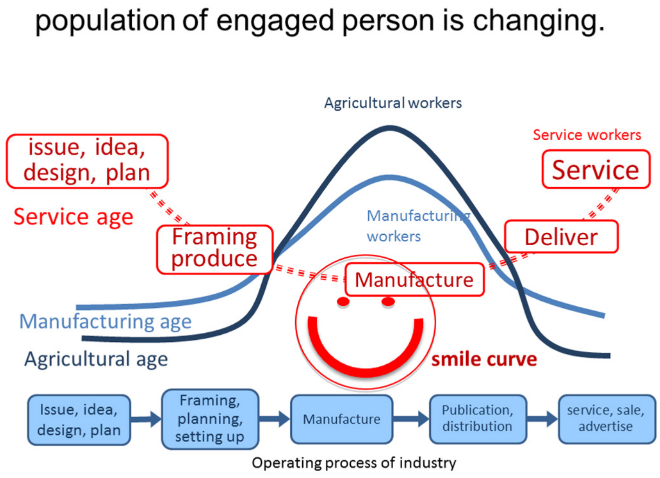


Figure 1: The industrial structure in Japan (smile curve)

In such a society, people require not only stored knowledge, but also the abilities of inquiry, collaboration, application of information, thinking, judgment, and expression, collectively called the smile curve. Therefore, students require active learning rather than listening and memorizing in school.

Japanese teacher education system

Traditionally, a teacher's life is divided into three stages in Japan. The first stage is getting a teaching certification by going through a university course (4 years), teachers college (4 years), or junior college (almost 2 years) authorized by MEXT and by collecting credits. He/she reads books and discusses policy, history, and problems with education while gaining a certain number of credits. In general, a student needs to obtain a certain number of credits for specific teaching subjects and professional subjects. With some credits and only a four-week teaching practice in school, any student can obtain a teacher's license. The teacher's license is valid for all prefectures in Japan, but getting the certificate does not guarantee being hired as a teacher. Teachers are recruited by each prefecture, in other words, by the government. For example, 178 461 students earned a teacher's license in 2009, but less than 10 % or only 17 272 students were employed as teachers (Figure 2, left).

The second stage is employment. Prospective teachers must take an examination to be hired by the local board of education. After they pass the examination and are employed, they start their teaching career. The third stage is on-the-job training in school, with little relationship with universities, meaning that the responsibility for teachers' development is handled by schools. In the traditional Japanese teacher education system, the pre-service and in-service training phases are separated. The university seems to be separated from the local board and schools (Figure 2, right).

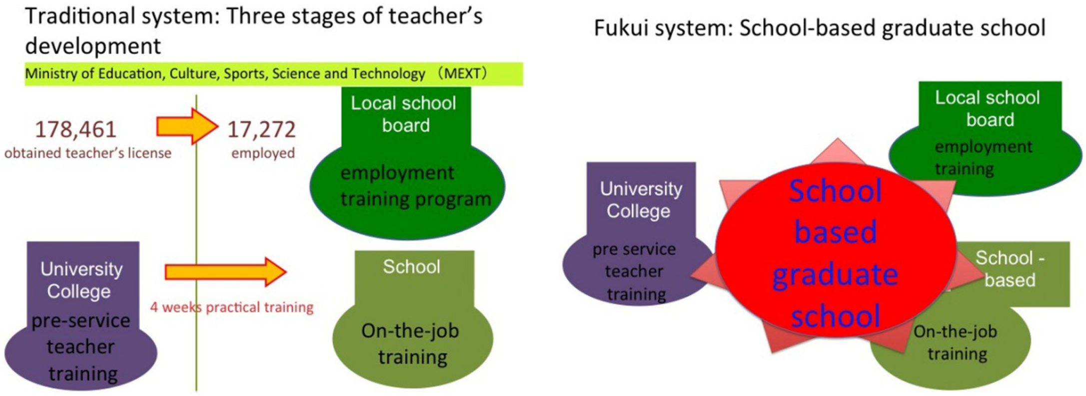


Figure 2: The three stages of the traditional teacher's development (left) and Fukui system (right)

System and curriculum of the Graduate School of Education, University of Fukui

The Graduate School of Education's Department of Professional Development of Teachers at the University of Fukui (DPDT-Fukui) was established in 2008. The system called "school-based, collaborative practice research" represents an innovation in the teacher training system (University of Fukui, 2002). In other words, the graduate school is taking place in schools. Instead of attending a university to learn teaching and learning by reading and hearing, in-service teachers train in school and invite university faculty members to discuss about the actual classroom situation. Pre-service teachers stay in the same school to learn teaching and learning together. In each school, lesson studies, action research, and collaborative learning are held. This arrangement is called a school-based graduate school system with a professional development school (PDS), which constitutes a major challenge in the innovation of teacher training in Japan (Figure 3).

Figure 3: School-based graduate school system (University of Fukui)

The curriculum of this graduate school is based on the viewpoint embodied in the concept of *community of practice* (Wenger et al., 2002). Both pre-service and in-service graduate students reflect on their own practices from the community of practice perspective. The main curriculum, known as "longitudinal, collaborative action research based in schools", consists of reflections on practice. Lessons are developed around discussions about teachers' own practices, listening to one another, reading case studies and theories, and writing about the processes involved in their own teaching practices. They share their practices, observe one another's practices, and reflect together. The research of the teachers and university faculty is based on practice.

Intern system for pre-service teacher training

Another major challenge involves the intern system for pre-service teacher training, which also takes place mainly in schools. Graduate students spend three days a week in school as interns (student teachers) and attend university two days a week for a year. This system also entails school-based, collaborative practice research; the main curriculum is the same as that of the in-service type, "longitudinal, collaborative action research based in schools". Each intern has a mentor who is an in-service graduate student in the same school. They open their classes with each other and attend the lesson study together. The professor goes to their school to participate in the lesson study. The new graduate school system tries to connect the three stages of the teacher's development.

Practice 1: Active learning in undergraduate courses using physics by inquiry

This section discusses the challenges of the undergraduate course using *physics by inquiry* (McDermott & Physics Education Group, 1996). From the viewpoint of teacher development as a lifelong process, learning physics actively to prepare teachers is needed. Developed by the University of Washington, physics by inquiry is designed as a set of laboratory-based modules to help teachers develop a functional understanding.

Undergraduate courses for pre-service teachers should be seen as the starting point of their lifelong teaching careers. However, undergraduate students have a strong belief that studying is just memorizing and reproducing knowledge, based on their prior experiences before entering university. Therefore, they should have an opportunity to engage in scientific inquiry. They cannot teach active learning without themselves experiencing how to learn actively.

We have developed a teacher training program aimed at deepening the scientific understanding of teachers-in-training and have investigated the effects of using physics by inquiry (Ishii & Yamada, 2012).

COMPARISON BETWEEN JAPANESE NATIONAL CURRICULUM AND PHYSICS BY INQUIRY

In the national curriculum (course of study), single-bulb circuits are introduced in the third grade; parallel and series circuits in the fourth grade; and voltage, resistance, and Ohm's law in the second grade in junior high school (eighth grade) (MEXT, 2008). In the third grade, students investigate how to light a bulb in a circuit. They engage in experiments, discuss them, and write down their conclusions. Conclusions such as "When a battery (+), bulb, and battery (−) are connected in a circle, electricity goes through and the bulb lights up" are written in the textbook.

On the other hand, physics by inquiry is designed to develop basic physical concepts and reasoning skills; construct explanatory models with predictive capability; and gain practice in relating scientific concepts, representations, and models to real-world phenomena (McDermot & Physics Education Group, 1996).

The developed program covers direct-current electrical circuits, a topic studied in the third and fourth grades of primary school.

PRACTICE AND INVESTIGATION

The developed program was implemented during the 2012 spring term for 15 weeks from April to July. The participants comprised 100 students at the Faculty of Education and Regional Studies of the University of Fukui (65 women and 35 men, aged 19–25). Most of the participants were in the first year of a four-year teacher education program for primary school. Some had studied physics before, and others had not.

The students' conceptual understanding was analyzed with pre-/post-tests by using DIRECT version 1.2 (Engelhardt & Beichner, 2004). The participants took identical tests before the practice and 1–4 weeks afterward. Although the students learned about electrical circuits, they forgot the meaning of circuit. In other words, they had difficulties in understanding what a circuit is.

The results of the pre-test and interview found that students have typical misconceptions such as "the battery delivers a constant current" and "the current is used up". This is actually reasonable because we often say "This battery is finished".

The participants were divided into 25 groups, consisting of four students each. They were fully engaged in the program and learned actively, even though it lasted 180 minutes. They enthusiastically discussed the topic and conducted experiments. From the pre- to post-test analysis, the mean score increased from 38.9 % to 46.4 %.

The discourse analysis revealed that most groups faced cognitive conflicts during the experiments and discussions about series and parallel circuits.

DISCOURSE ANALYSIS

In the lesson about physics by inquiry, the students used their own concepts to hypothesize about and reason through the phenomena. At the experiments, they faced cognitive conflicts as they were unable to explain any further using their concepts. They discussed and did the experiments again and again. Finally, they changed their concepts and explained the phenomena by themselves. This means they constructed the concept socially.

A brief example of four students' discussion in a parallel circuit experiment concerns the question:

"Compare the brightness of each of the bulbs with the brightness of an identical bulb in a single-bulb circuit" (McDermot & Physics Education Group, 1996: p. 395).

Figure 4: The students discussing about the current in a parallel circuit

Figure 5. Shows a typical discussion dialogue illustrating cognitive conflicts between a previous concept and a real phenomenon. Figure 4 shows the discussion and equipment on the table.

Student A:	I don't know why. I wonder why the bulbs don't get dimmer when they're connected in parallel.
Student B:	But the current at the battery should be the same as a single circuit.
Student C:	The two bulbs lit up but the current is the same. Is this OK?
Student A:	I think the current should be twice as much, to compare with a single circuit.

Figure 5: Dialogue about the current in a parallel circuit

Student B presented the strong belief that a battery provides the same current anytime. However, Student A asked the group why it is not consistent with the phenomenon. After the discussion, they started to investigate the brightness of a single circuit again.

FINDINGS FROM PRACTICE IN UNDERGRADUATE COURSES

Physics by inquiry is engaging and provides the opportunity to learn physics in depth. It is effective for Japanese university students. It provides ideal experiences of reasoning and facing cognitive conflicts. Pre-/post-test results indicated that conceptual difficulties were considerable and widely encountered. The discourse analysis suggested that expressing a concept elicited their own thoughts, exchange of ideas, and reconstruction of the concept. Step-by-step exercises led the students to a conceptual understanding. Moreover, teaching assistants were able to serve as facilitators rather than knowledge tellers. From the discourse analysis, many students formulated a concept of the conservation of electrical current in a circuit.

To encourage active discussion and better understanding, relations within the group and an atmosphere allowing free expression without stress are important. Especially when someone says "I don't know", the discussion becomes active. To promote inquiry, facilitation such as "teaching by asking" is effective.

PRACTICE 2: LESSON STUDY IN A SCHOOL WITH A LOCAL TEACHERS' COMMUNITY

This section provides an example of a lesson study, which occurred on October 17, 2012 in Fukui Prefecture. Nearly 30 teachers gathered from all areas of Fukui Prefecture and other prefectures. The members of the school board, university professors, pre-service graduate students, and undergraduate students also participated in the lesson study. As usual, the lesson study consisted of a research lesson and debriefing, and it was conducted on the same day.

THE RESEARCH LESSON

The topic was "How is light reflected?" The objective was to explore and understand how light is reflected. The target comprised first graders in junior high school (12 and 13 years old). There were 14 boys and 14 girls divided into 7 groups of 2 boys and 2 girls each. This lesson lasted for 70 minutes.

The lesson had four phases.
Phase 1. Observe the "ball" reflection.
Phase 2. Conduct a group discussion.
Phase 3. Share ideas in class.
Phase 4. Apply the rule to "light" reflection.

Figure 6 shows Phase 1. The teacher assigned the day's task to the class: "Let's play billiards. Shoot a ball into a pocket."

Figure 6: Phase 1: Observe the "ball" reflection

The word "billiards" sounded interesting for the students. Many students became curious about billiards and wanted to play the game. Each group had an experiment table and a whiteboard. They started to examine how a ball is reflected. They observed the ball and tried to find the role of reflection.

Figure 7: Phase 2: Group discussion and the teacher

Figure 7 illustrates the group discussion in Phase 2.

Each student expressed and discussed his or her thoughts regarding the words, pictures, and diagrams on the whiteboard to discover the role of reflection. The teacher visited each group to listen to the students' discussion and to ask occasional questions. The participants observed and listened closely to one or two group discussions.

The students discussed how to present their findings in front of the whiteboard.

Figure 8 shows the students sharing ideas in the class (Phase 3).

Some of the groups explained their findings to the whole class using their whiteboards. They shared that all of them found the same principle, that a ball reflects the same angle. Finally, the teacher explained the name of the incident angle.

The teacher asked the students to apply the rule of ball reflection to light reflection (Phase 4, see Figure 9). "Let's play another game. How do we light the doll in the center with a flashlight and eight mirrors?"

Figure 8: Phase 3: Share ideas in the class

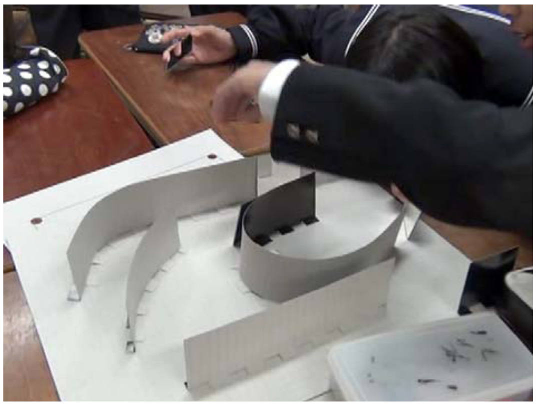


Figure 9: Phase 4: Apply the rule to light reflection

Debriefing after lesson (collaborative reflection)

After the lesson was finished, the participants discussed the students' learning process in small groups. They sat at the same tables from which they observed the students and shared their findings (Figure 10).

Figure 10: Debriefing (group discussion)

The participants held discussions based on their observations of the students' performance. An example is shown in Figure 11.

Teacher A: “At first, they didn't realize the rule of reflection. But when this boy succeeded in getting a ball into the pocket, the girl found the path of the ball. After that, they started to discuss actively.”

Teacher B: “I saw the girl so precisely. She looked very curious. When they started to talk in front of the whiteboard, she took the pen immediately and started to draw a diagram. But they didn't have the idea of the difference of [the] angle.”

Teacher C: “The students didn't express the incident angle on the whiteboard. But they discussed the length of the pathway. I think they noticed that the angle is two times the incident angle. We can consider this to be finding the rule of reflection.”

Figure 11: Dialogue excerpt from a group discussion

After the small-group discussions, one teacher represented each group to share what was discussed in their respective groups (Figure 12).

Figure 12: Debriefing (sharing of group discussions)

Findings from the lesson study practice in the local teachers' community

At each table, each participant discussed the performance of the students. The teachers must observe the students' learning and present their findings. Presented with the actual lesson, everybody learns how students learn.

Professional development, which is asked for by in-service teachers, must be supported by practical and collaborative research from organizations that face actual problems and are appropriate for professionals. The cooperation and collaboration of universities, education boards, and schools should form a framework for new teacher education. Through these practices, the university and local professional networks can support the learning community in schools and the distributed community of local teachers.

The new trend in the lesson study focuses on the learning process of students, not the teacher performance. The experience of discussing the learning process of students with colleagues is supported and facilitated by the university. If colleagues construct a learning community, teachers will be stress-free and try to promote students' learning.

Practice 3: Practice and Reflection of an Intern — Yosuke's story

This section presents an example of one intern's lesson study (Sasaki, 2011). Yosuke Sasaki, aged 23, was a graduate student at the University of Fukui. He was an intern at Shimin Junior High School, the same school where practice 2 was held. Yosuke's practice was about sound for the first grade of junior high school, which occurred in September 2010.

Yosuke's Story — Sound

Before the lesson, Yosuke came to the university to discuss and make a lesson plan covering the topic of sound. He decided that the first lesson would be about loudness, and the second lesson would be about high and low frequencies, because these topics seemed easy (Figure 13).

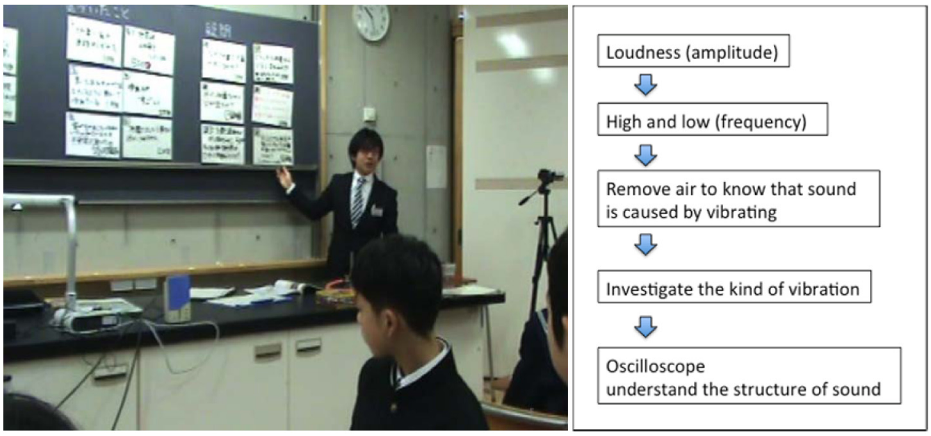


Figure 13: First lesson and first lesson plan of Yosuke (an intern)

At the first lesson, Yosuke taught about loudness and prepared the second lesson as planned. At the second lesson, Yosuke asked the students to make various sounds with a wine glass and mono cord and to think about what the sounds were like. He told them: "Loudness is amplitude, as you learned yesterday. Let's explore high sound and low sound today." At that time, he believed that the students understood that loudness is amplitude because he had "taught" it to them in a prior lesson (Figure 14).

Figure 14: Second lesson about high and low frequencies

Figure 15: Yosuke's confusion about why the students were playing

The students started to make various sounds and investigate them. However, some students made loud, high, small, and low sounds randomly. They just looked like they were playing with instruments. They did whatever they wanted and did not seem motivated (Figure 15).

Yosuke was confused and asked himself: "Why aren't they examining high and low? Why are they making various messy sounds? Why don't they follow my assignment?" He went to each group to facilitate their investigation. At this point, he wanted students to conduct the "right" type of investigation.

Many colleagues observed this lesson. Another intern listened to the students talking; a mentor (in-service graduate student) observed what they were trying to do.

After the lesson, Yosuke reflected on his lesson with the professor, other interns, and his mentor (Figure 16).

Figure 16: Debriefing with other interns, mentor, and professor

After the lesson, Yosuke and the observers collaboratively reflected on the lesson. They exchanged their observations about each student's actions and words, as well as discussed how and what they learned. The mentor told him, "The pupils analyzed sound their own way, although they looked like they were playing." Another intern said, "The boy I observed seems to be confused about what to do. Does the pupil recognize the difference between frequency and loudness?"

Yosuke realized that the students wanted to investigate by themselves. They were not unmotivated; they merely followed their own interests, not the teacher's. He realized that he just pushed the inquiry process to the students. He tried to reconsider and redesign the lesson plan.

At the last lesson on sound, Yosuke tried to connect content knowledge with the students' interest. He arranged the oscilloscope to analyze a pupil's voice easily. He asked the students, "What does the oscilloscope show?" They then investigated more eagerly and found the wavelengths of high and low sounds (Figure 17).

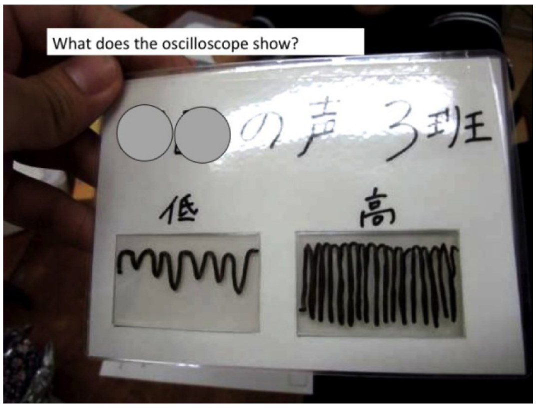


Figure 17: Last lesson: investigation on what the oscilloscope shows

After all the lessons were finished, Yosuke reflected again on his own practice. He realized his insistence on his first lesson plan; however, to facilitate diverse students' learning, he should apply more flexibility in creating the lesson plan. Then he reconstructed the content of the lesson by portraying sound as a dynamic structure (Figure 18).

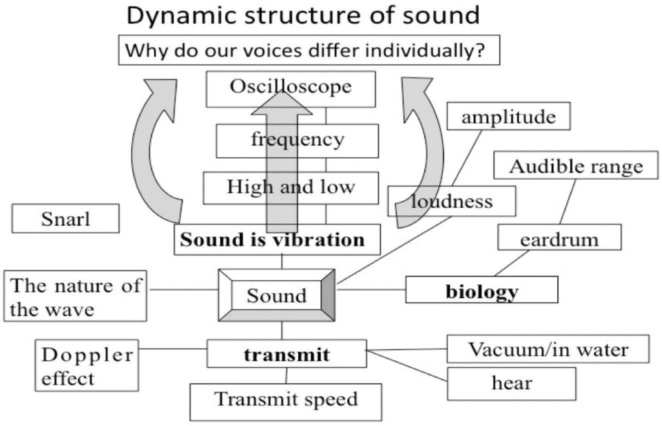


Figure 18: Dynamic structure of sound after Yosuke's reflection

Through this process, he was able to address any student reaction — and the reactions were quite varied. This reconstruction of the lesson content is an important pedagogical phase. Lesson plans do not fit all classes, especially when they involve incorporating active learning into a lesson. It is difficult to teach this fact to novice teachers or students unless they practice it themselves.

Creating such a dynamic structure to design a lesson is considered one of the teacher's skills, called "pedagogical content knowledge (PCK)" (Shulman, 1987). It is said that teachers need a lot of experience and time to acquire PCK.

STRUCTURE AND LEARNING COMMUNITY TO SUPPORT INTERNS' DEVELOPMENT

How did Yosuke acquire PCK in such a short time? The structure of the curriculum and the learning community support the interns' development. As shown in Yosuke's year cycle, interns repeat practice and reflect on the lessons many times (Figure 19).

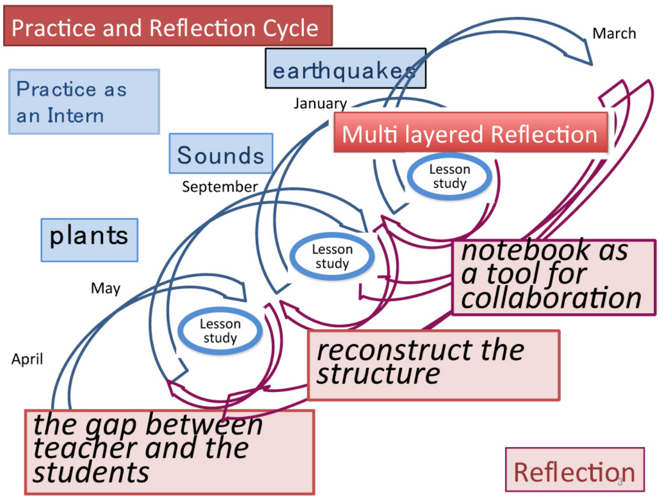


Figure 19: Year cycle of practice and reflection of an intern

The lesson study provides interns with many opportunities for practice and reflection in the course of one year. Yosuke repeated three practice sessions in one year: plants in May, sounds in September, and earthquakes in January. During each practice, many colleagues, professors, and the mentor observed his lesson and reflected on it together. At the first lesson, Yosuke encountered a gap between the teacher and the students. Through his reflection on his second practice on sound, he realized the importance of reconstructing the topic before designing a lesson plan. In his third practice on earthquakes, he used the whiteboard and students' notebooks as tools for communication and facilitation of the students' inquiry.

Yosuke wrote about his practice:

The main and important thing in my learning process is reflection and community. My community is various, as intern colleague, PDS, graduate school, and science seminar, etc. I talked with different people, and think again, write my practice and thought. My thought became clear and tacit knowledge comes up to be shown. (Sasaki, 2011).

The yearlong cycle of an intern is designed to enable him/her to do practice and reflection repeatedly. The curriculum of interns is designed to enable them to observe lessons, teach, perform special activities, etc., in school. Once a week they gather at the university to share their reflections together with professors. They read books and discuss and write their theses with in-service graduate student teachers and university faculty during weekends and the summer and winter holidays. Such repeated reflections with different colleagues have been named "multilayered reflections".

FINDINGS FROM PRACTICE OF LESSON STUDY IN THE LOCAL TEACHERS' COMMUNITY

The reflection and practice cycle creates opportunities to develop the pre-service students' reflective thinking skills and support their potentials as professionals. The interns' thoughts become integrated and based on multiple perspectives. Student teachers establish their beliefs and theories through integrating experiences and knowledge.

At the lesson study, not only interns but also mentors and professors learn a lot from students learning in the classroom. Therefore, the intern system presents one of the challenges to cultivate a learning community.

CONCLUSION

This report has discussed active learning in teacher training with three practices at Fukui Prefecture and the University of Fukui. The results show that to cultivate a learning community, each participant should learn actively from the lesson study and communicate dynamically. The students learn actively from the phenomenon with group discussions in the first practice. At the graduate school, all participants — both students and teachers — learn active, collaborative, and reflective strategies in the practice.

The National Science Education Standard notes the standards for professional development:

Although learning science might take in a science laboratory, learning to teach science needs to take place through interactions with practitioners in places where students are learning science, such as in classrooms and schools.

Provide regular, frequent opportunities for individual and collegial examination and reflection on classroom and institutional practice (National Committee on Science Education Standards and Assessment, 1996).

In the lesson study, observing and discussing the students' learning in a collaborative manner constitute active learning for the teachers. To cultivate and promote a professional learning community, it is vital to provide opportunities for collaborative reflection in the classroom, such as through the lesson study and repeated cycle of practice and reflection. The curriculum of the University of Fukui is designed with active, collaborative, and reflective engagement in the professional learning community.

In conclusion, it is clear that collaborative and continuous learning based on "reflective practice" is the essence of teacher training. To enhance awareness of how students learn, collaborative reflection on the lesson by the professional learning community is effective. If colleagues build a learning community, teachers will have their stress levels reduced and will try to promote students' learning. The university can function as a facilitator to cultivate a professional learning community. Both pre-service and in-service teachers develop pedagogical content knowledge through repeated practice and reflection.

ACKNOWLEDGEMENT

The author gratefully acknowledges all the teachers and students who were involved in the lesson study and collaborative research. She also thanks Dr. Yoshihide Yamada and Mr. Yosuke Sasaki for participating in this program; without their cooperation, this project would not have been possible.

REFERENCES

Akita, K. (2012). Building learning and caring communities through high-quality lesson studies. [online]. Available from http://www.walsnet.org/2012/keynote-speakers.html

Engelhardt, P. & Beichner, R. (2004). Students' understanding of direct current resistive electrical circuits. *American Journal of Physics*, 72(1), 98–115.

Hargreaves, A. (1994). *Changing teachers, changing times: Teachers' work and culture in the postmodern age.* Teachers College Press.

Ishii, K. (2011). The professional development of a science teacher as a reflective practitioner. *Studies in and on Teacher Education*, 4, 243–254 (in Japanese).

Ishii, K. & Yamada, Y. (2012). Teacher training program using active learning based on physics by inquiry. *WCPE 2012 Proceedings.*

Lewis, C. (2012). What is lesson study? Lesson study group at Mills College. Available at http://www.lessonresearch.net/index.html

Lieberman, A. & Miller, L. (2008). *Teachers in professional communities.* Teachers College Press.

McDermott, L. (1996). Physics Education Group at the University of Washington. *Physics by inquiry Volumes I and II.* New York: John Wiley & Sons, Inc.

Ministry of Education, Culture, Sports, Science & Technology in Japan. (2008). *Improvement of academic abilities (Courses of study).* Available at http://www.mext.go.jp/english/elsec/1303755.htm

Murata, Y. & Yamaguchi, M. (2010). *A bilingual text: Education in contemporary Japan — System and culture.* Toshindo.

National Association for the Study of Educational Methods. (2011). *Lesson Study.* Keisuisha.

National Committee on Science Education Standards and Assessment. (1996). *National Science Education Standard.*

Organisation for Economic Co-operation and Development. (2007). *Programme for International Student Assessment (PISA) 2006 science competencies for tomorrow's world.* Available at http://www.oecdtokyo2.org/pdf/theme_pdf/education/20071204sg_speech.pdf

Sasaki, Y. (2011). The process of constructing a lesson with collaboration and reflection. (in Japanese).

Schön, D. A. (1984). *The reflective practitioner: How professionals think in action.* New York: Basic Books.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of new reform. *Harvard Educational Review*, 57, 1–22.

Stigler, J. & Hiebert, J. (1999). *The teaching gap: Free press reprint.*

University of Fukui, Faculty of Education and Regional Studies. (2002). *Design of Japanese teacher education reconstruction in 21st century.* Center for Network and Collaboration Supporting Regional Education Reconstruction.

Wenger, E. et al. (2002). *Communities of practice: A guide to managing knowledge.* Harvard Business School Press.

Kyoko Ishii
Faculty of Education, Tamagawa University, Tokyo, Japan
Department of Professional Development of Teachers,
Graduate School of Education, University of Fukui, Fukui, Japan

Selected papers

Scientia in educatione 8(Special Issue), 2017
p. 120–128
ISSN 1804-7106

Science Interval Project: We Can Teach and Learn Physics During the Leisure

Francisco Adeil Gomes de Araújo, Meirivâni Meneses de Oliveira, Eloneid Felipe Nobre

Abstract

The break between classes, still seen as an unproductive interval of time, in recent years, has been a cause of worry to the school community. The Science Interval Project aims to combine the science education with leisure time during the interval school, attracting the students for a time of learning and discovery. Specifically, the project aims to provoke and inspire the student to discover, build and give new meaning to knowledge and present to the school community the work developed in the classroom by the teacher and his students.

Key words: secondary education: upper, method and strategies of teaching, low cost experiments, teaching and learning physics.

INTRODUCTION

Almost every physics teacher has to face the constant challenge of teaching a subject for which students generally have little interest. The lack of students' interest in studying and learn Sciences, in general. Physics, especially, is a great problem in the secondary schools, mainly in the public schools. The teachers are constantly fighting against this lack of student's interest, lack of structure that do not provides opportunities appropriate laboratory classes and currently some Brazilian teachers have face another difficulty in the exercise of their profession: the violence in schools. The enhance of violence in the school environment has been a source of concern for the whole school community: of the 456 public schools in the city of Fortaleza, capital of Ceará, in northeastern Brazil, 35 are in hazardous areas.

With the intention to collaborate to improve this state of affairs, we decided to develop and implement The Science Interval Project at a public school in one of the poorest neighborhoods of the city of Fortaleza. The project is being conducted in a Primary/Secondary School, located in Bom Jardim, neighborhood in Fortaleza. The region is known for high rates of violence and the school has experienced the loss of students because of fights between gangs and use of drugs. This violence came to the school environment, for example, by aggressive jokes and fights during the interval of the classes. Searching a solution to this situation, we developed this project in school seeking to involve the students in activities that awake their interest and can be performed in a cooperative way. On the last Friday or Wednesday of each month, the projects and experiments developed by teachers and students in the classroom and in the science laboratory are presented in the schoolyard. The presentation is made by the students who were chosen by their teachers, or those who have expressed an interest in participating. The use of low cost experiments is prioritized, because the school does not have a suitable science laboratory.

OBJECTIVES

The main objective of this project is to combine the science education with leisure during the time of the interval school, attracting the students for a time of learning and new discoveries in the 20 minutes of interval between classes, without forgetting its purpose that the students can relax and have fun, before continuing their scheduled classes.

Specifically, we also intend: to provoke and inspire the student discovers, builds and gives new meaning to knowledge; to submit to the school community the work developed in the classroom by the teacher and his students; to create a culture of practical classes in school, beyond the traditional lectures using only crayon and blackboard; to awake the curiosity and taste for science among the students.

METHODOLOGY

The project began in May 2012, in a public school for basic education, located in a poor neighborhood in Fortaleza, capital of Ceará, in Northeast Brazil. Thinking of using not only the classrooms but also the gap of time between the classes, arises the project that aims to lead the science in the Interval of the classes, moments otherwise often occupied by fights, and even dangerous accidents.

The teacher is the responsible for development of ideas and practical activities in the classroom. The experiments are developed by the students, with helping of teacher, about the contents studied. To construct the experiments, the students are tasked to collect, themselves, the materials, and the use of low cost experiments is prioritized.

Once a month, all experiments are presented to school. The students are in charge of presenting the experiments in the schoolyard during the interval between classes. They have the support of their teacher and of the science lab coordinator. The presentation of the experiments in the schoolyard, is made by the students who were chosen by teachers, or by those students who have expressed an interest in participating.

When an experiment cannot be repeated during the interval, such as the dissection of a bull's eye to understand the optics of human eye, photos of experiment are available on the blog of project (http://intervalociencia.blogspot.com.br/).

On the day of the presentations, the students are in charge for presenting, explaining the experiments and guide the other students who visit the tables of experiments and to return to their rooms when the interval ends. This occurs both in the morning and in the afternoon. They are also responsible for the organization of experiments and materials in the yard. The teacher only accompanies the process, in order to help them, if necessary.

The use of low cost experiments is prioritized, because the school does not have a suitable science laboratory, but some materials are acquired in the science laboratory of the school.

The activities began on May 2012, during the night class, with a lecture on Astronomy, delivered by members of the Astronomy Club of Fortaleza, followed by observation by students of the Moon and Saturn through telescopes.

The project was continued with presentations of experiments on reflection and refraction of light, and exposure of photos made with dark chambers built by students in 9th grade. This material was used by the whole school community, in the morning and afternoon.

The students presented various experiments with balloons, to demonstrate many kinds of contents, such as atmospheric pressure, heat transfer, circular motion and friction.

On July the project was stopped because of school holidays. The activities returned in August, but we had little time to develop new works since the attention of teachers and students were directed to the bimonthly evaluations.

The project began again on September. The teacher, in his classrooms of geometrical optics, developed, with his students, a photography project, aiming at building a machine called Pinhole Camera. The students built their own cameras using matchboxes, hair clips, among other materials. Then they chose a theme to photograph and sent to reveal. The photographs were exhibited at the school throughout the month.

During the month of September in addition to Physics, the project also included the participation of other experiments in the areas of Chemistry and Biology. The students extracted the DNA from some fruits, they performed analyzes of urine and also presented experiments on surface tension, density, condensation and sublimation. Even a student in the 6th grade of elementary school showed a robot he built using toothbrushes, and 9th grade students explained the decomposition and interference colors through huge soap bubbles.

With the development of the project, in addition to experiments on the subjects developed in the classroom, some students also presented experiments they searched at the internet, developed with the help of the coordinator of the science lab. The students presented experiments on phosphorescence and fluorescence, optical illusion, 3D technology, density of liquids. They built a periscope and some students built batteries using lemons and copper coins. As an activity linked to Biology, the students calculated the body mass index of their classmates.

During the month of November, the project was not presented at the school because the class teacher have been absent to attend the Meeting of the Physicists of the North and Northeast, a regional conference that annually gathers the community of physicists, researchers, students and teachers from the North and Northeast of Brazil.

During December, the Doppler effect was been studied, both for sound and light. Students used computer simulations and simple experiments to explain how astronomers discovered the expansion of the universe. In addition, was organized a competition of rockets, built by the students using plastic bottles. In the construction of rockets were addressed the three laws of Newton.

Analyses and Results

The experiments were performed by approximately 80 students, with the guidance of the class teacher. Among these 80 students, 16 were selected to be monitors, which were in charge of the presentation of the experiments. The total number of students participating in the project's first phase was 204, including the students who performed the experiments, the monitors and the other students of the school who participated by attending the presentations and visiting the stands with the experiments, only attending the exhibitions.

The project also included the participation of teachers from several areas: three of Physics, two of Chemistry, two of Biology, three of Mathematics and still, one of Geography, which emphasizes its multidisciplinary perspective.

We conducted a survey with the 204 students to verify if the objectives of the project were being met. The results are shown below.

First of all, we wanted to know the point of views of students on the new method of learning. Their responses are showed on the Figure 1.

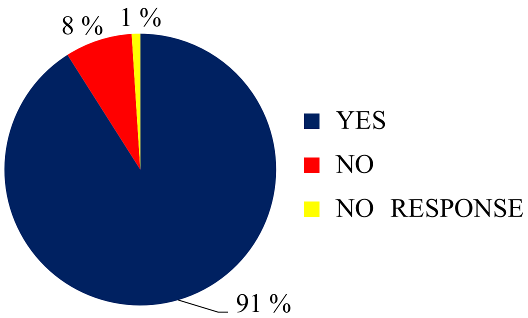


Figure 1: During the Science Interval you think you can learn science in a fun way?

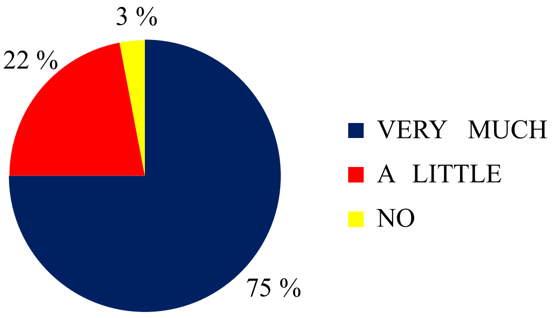


Figure 2: Do you participate in the moments of the Science Interval, visiting the tables and performing the experiments?

186 students, about 91 %; said Yes. 16 students, about 8 %; said No, and 2 students about 1 %, Did not answer.

With respect to the participation of students, we obtained the following results, showed on the Figure 2.

154 students, about 75 %, have participated a lot of the presentations of the experiments. 44 students, about 22 %, participated a little, and only 6 students, about 3 % did not participated.

Finally, when we asked if they thought that the project has contributed to an improvement in their performance in Physics classes, we obtained the following group of responses:
154 students, about 75 %, said Very much. 44 students, about 22 %, said they learned somewhat. Only 6 students, about 6 % thought the project did not contribute to their learning.

The schedules of classes in the Brazilian schools are divided in periods: morning, afternoon and night. This information, related with the last question, were given mainly by the students of morning shift, composed by eleven groups. From these, two groups are formed by high school students and one of 9th grade of elementary school.

Only the high school students and those from the 9th grade participate regularly in the project, since these are the students who have Physics Chemistry and Biology in their school curriculum. This became more evident when analyzing the students' responses for the third question. When asked if the project was contributing to an improvement in their performance in science classes, where 75 % of students responded very much, 22 % said somewhat and 3 % said it had contributed nothing.

We also monitor the student's results in the assessments of Sciences and Physics exams throughout the year 2012, when the project was implemented, compared to the results obtained in 2011, before the implementation of the Project.

The results are showed on the figures below.

To the students of the 9th grade, which were evaluated in the contents of Sciences: Physics, Chemistry and Biology, we see the following results:

The graphics in yellow refer to the results of 2011 and green, the year 2012, when the project has been applied.

The results of assessments for the students in the high school level are showed in the graphs bellow. This group was composed by 27 students. The graphs show the results obtained in the assessments of Physics.

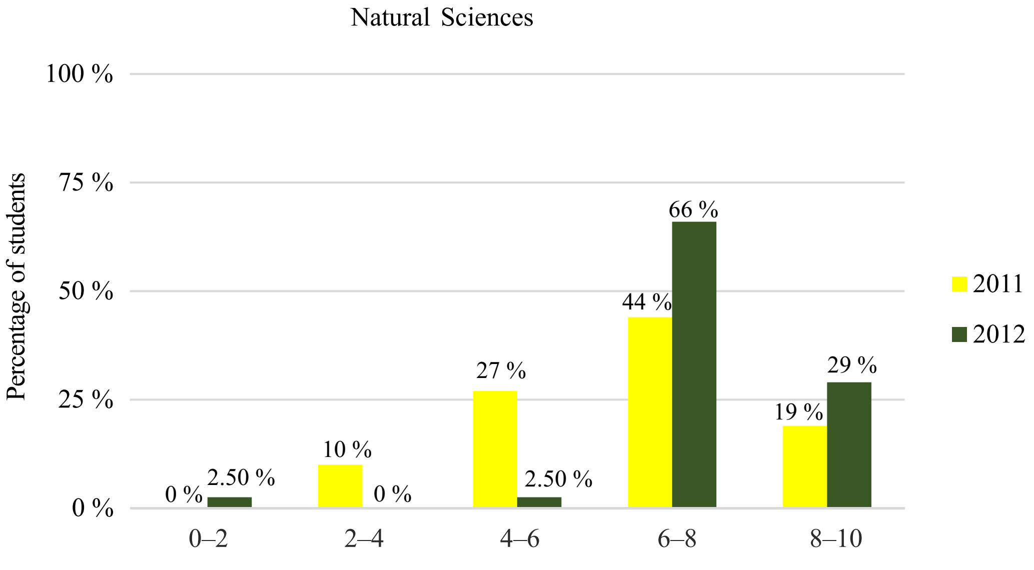


Figure 3: Results of bimonthly assessments of Sciences (March and April)

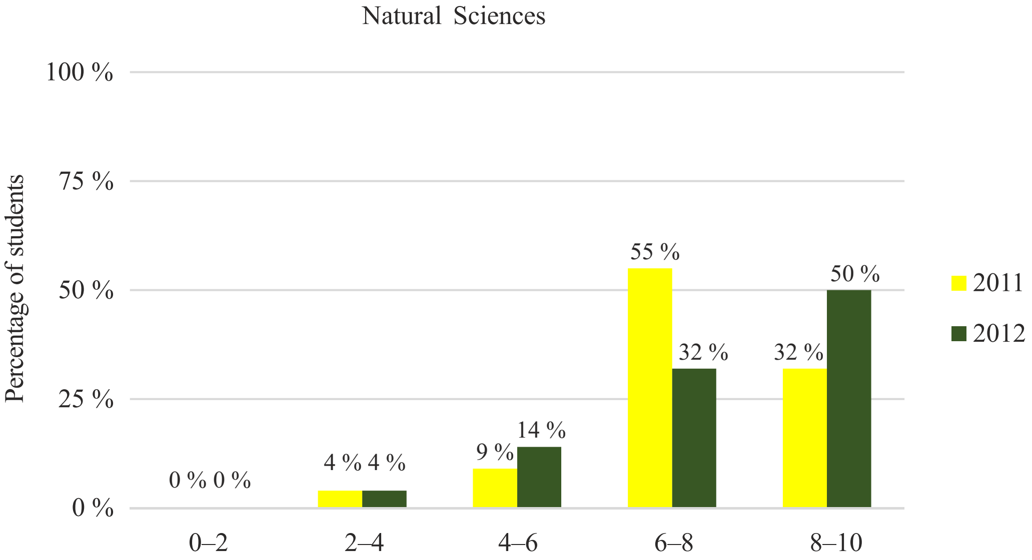


Figure 4: Results of bimonthly assessments of Sciences (May and June)

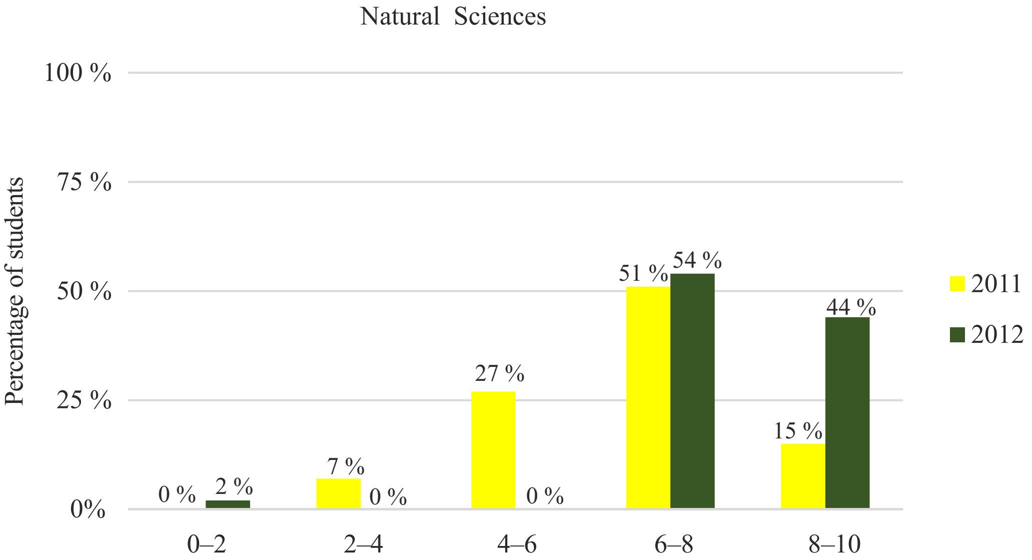


Figure 5: Results of bimonthly assessments of Sciences (August and September)

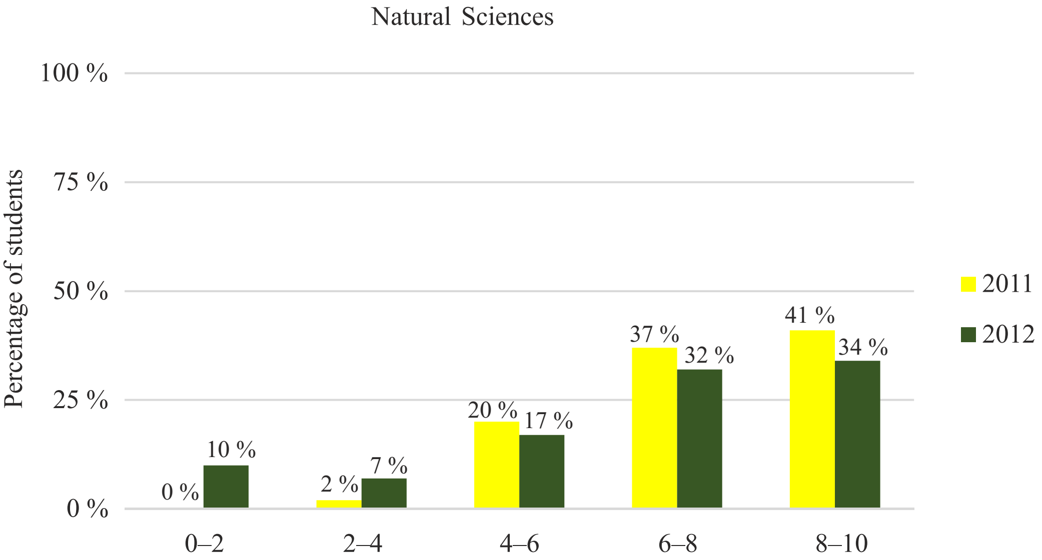


Figure 6: Results of bimonthly assessments of Sciences (October and November)

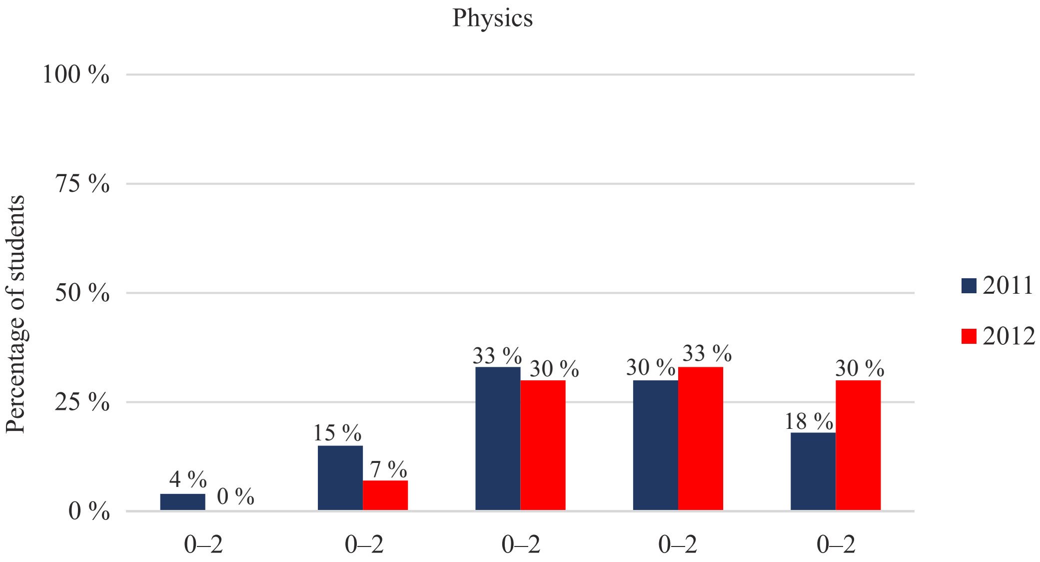


Figure 7: Results of bimonthly assessments of Physics (March and April)

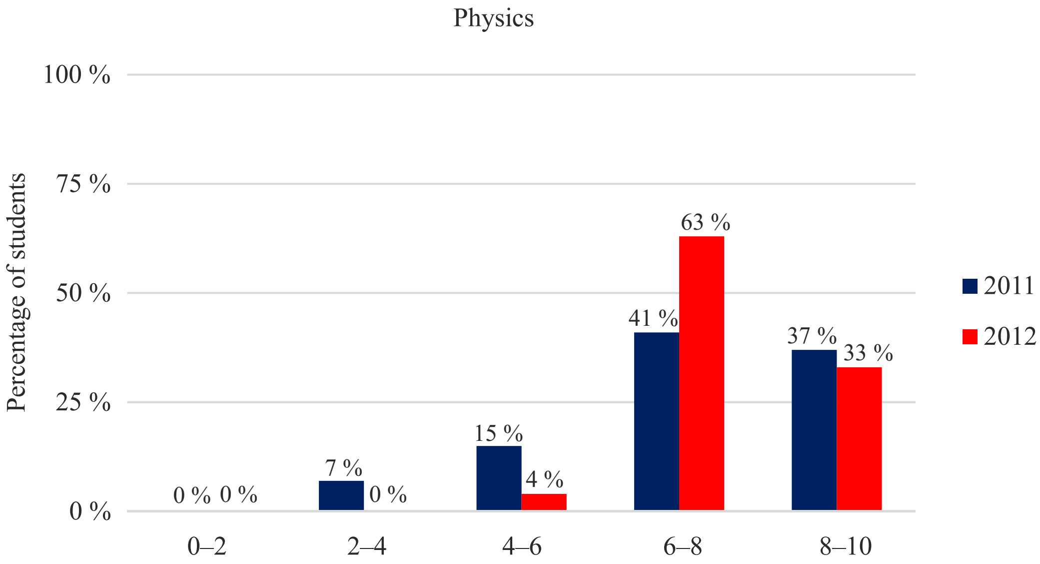


Figure 8: Results of bimonthly assessments of Physics (May and June)

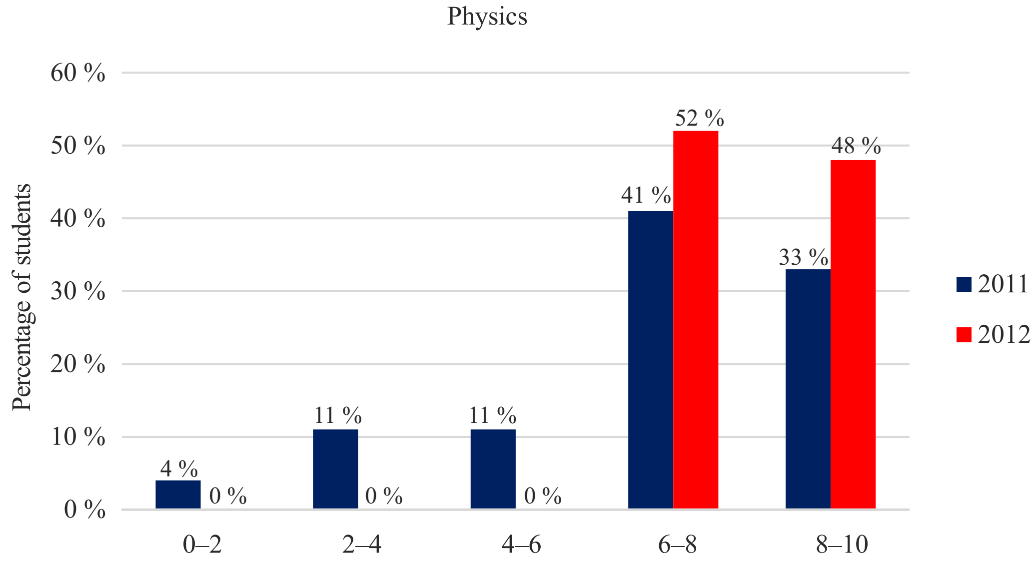


Figure 9: Results of bimonthly assessments of Physics (August and September)

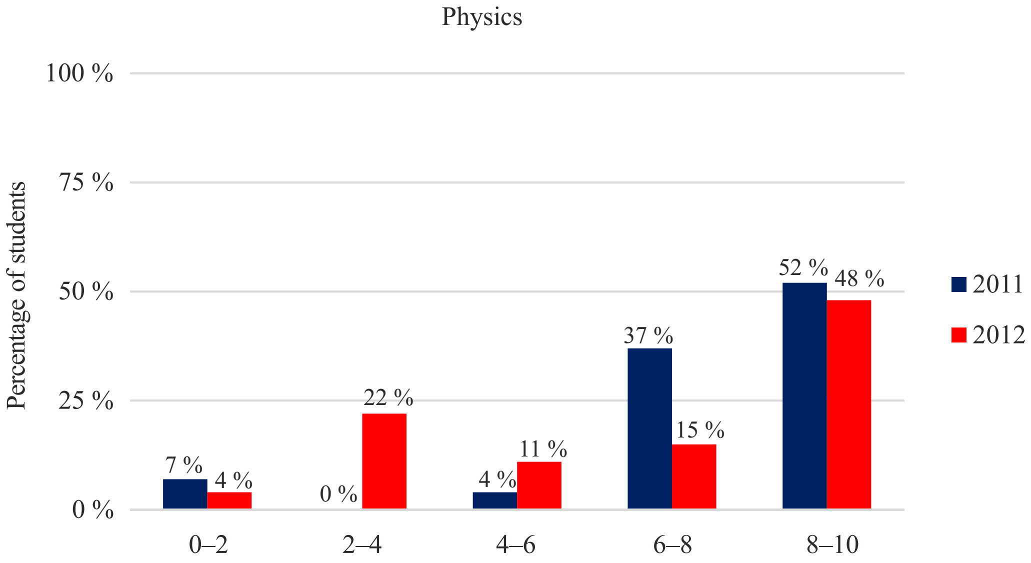


Figure 10: Results of bimonthly assessments of Physics (October and November)

The graphs show that, in general, the results obtained by the students in the assessments are better than that before the Science Interval Project was applied. The students were more involved and interested. Even the results of the fourth bimonthly assessments, which show in 2012 grades less than that of 2011, can be explained. In this period, we organized a competition with all the Physics contents, when the students had the opportunity to show the experiments related with the contents they learned during the year. In this latest assessments the tests were more extensive, covering the contents of the whole year and not just those seen in bimonthly periods.

We hope to get more data to analyze how the project has contributed to a more meaningful learning for the student.

Final remarks

The Science Interval Project is still a pilot project, and we intend to use the time of interval between the classes as another learning moment, but the results obtained until now suggest that the project is reaching its objectives.

Recent studies show that the method in which students perform the experiments by themselves and also themselves present them to their colleagues, results in a more meaningful learning, accumulating experiences that reach 90 % of apprehension of the contents. Therefore, it is important to orientate the students to be more active in the process of teaching and learning.

The use of low cost experiments, because the school does not have an appropriate science lab, the act of teaching what they have learned, to present a project or experiment, leads the students in a remarkable improvement in their behavior, attitudes and self-esteem, and consequently in their learning.

The project has been changing the school routine. The whole school community is committed towards continuing the project, making it a routine. Teachers, students, all school community begin to understand that so important than only improving school performance, with good grades, is to make the student be able to construct their own knowledge and also changing his attitude in the society. We cannot forget of the contribution for the experimental classes. The project surely contributes to enhance the experimental classes, because the schools, in general, don't have an appropriate science lab.

Initially there was only one school and its 204 students involved in the project. Some dsses 204 students, were active, performing the experiments and acting as presenters of the experiments for the school community. Others only attended the exhibition. Nowadays the project is been presented to several schools and we have more than 400 students envolved.

Besides being taken to secondary schools, currently the project was adapted to be presented as workshops low cost experiments, as a complementary activity to the students of Physics of Federal University of Ceará, focused to teacher education.

REFERENCES

Moreira, M. A. & Masini, S. F. E. (2001). *Meaningful learning: The theory of David Ausubel.* São Paulo: Centauro.

Neuenfeld, D. J. (2003). School break: What happens far from the teachers' eyes? *Maringaá*, 14(1), 37–45. Available at http://periodicos.uem.br/ojs/index.php/RevEducFis/article/viewFile/3479/2512

Teixeira, M. S. A. & Vital, M. L. S. (2003). Experimental activities in physics teaching: Different approaches, different purposes. *Brazilian Journal of Physics Teaching*, 25(2).

FRANCISCO ADEIL GOMES DE ARAÚJO
Secretaria of Education of the State of Ceará
Federal University of Ceará

MEIRIVÂNI MENESES DE OLIVEIRA
Secretaria of Education of the State of Ceará

ELONEID FELIPE NOBRE
Federal University of Ceará

sciED
Scientia in educatione 8(Special Issue), 2017
p. 129–138
ISSN 1804-7106

Investigating with Concept Cartoons: Practical suggestions for using concept cartoons to start student investigations in elementary school and beyond

Ed van den Berg, Patricia Kruit

Abstract

Concept cartoons can be used to diagnose misconceptions and stimulate discussion of basic concepts and phenomena. However, the teacher can also present a cartoon and then ask students to think of experiments to further investigate the phenomenon shown in the cartoon. Our experience is that students from age 9–18 very quickly come with creative ideas and start investigations. That is, of course, only the beginning. The teacher will have to follow the work of the students closely and help them to develop their investigation skills and critical thinking. In the workshop you will experience how to start an investigation with the cartoon and then we will focus on how to use formative assessment to improve the work of students.

Key words: concepts, evidence, reasoning, inquiry, designing experiments, concept cartoons.

Workshop presented at the ICPE-EPEC Conference on Physics Education, Prague, 5–9 August 2013.

INTRODUCTION

Concept cartoons (Naylor & Keogh, 1999, 2012; Naylor et al., 2007) are a popular means to stimulate reasoning with science concepts among children from the age of 8–18. The concept cartoons also provide a natural context for children to design their own experiments rather than do cookbook experiments.

> During my first experience in grade 4 I showed them a glass with cold water and added some ice cubes. They reacted well with observations and experiences. Then I introduced the cartoon (see appendix) and asked them whether they could think of experiments to further investigate the phenomenon. They decided in no time what they were going to do and rushed off to search for beakers and other things they needed. When they were together again, and I asked a few questions, it quickly became obvious to them that their original idea was not good enough and that they had to do some more thinking. They thought more and came up with interesting and meaningful experiments.

Show children a concept cartoon, have some discussion, and then ask them to design an experiment to provide evidence for or against one of the statements in the cartoon, and the children rush off to set up an experiment. They get into the activity so quickly that the teacher even has to slow them down and force them to think through their ideas more carefully and that is where the challenge is, to get them to think and to reason and yet maintain the enthusiasm.

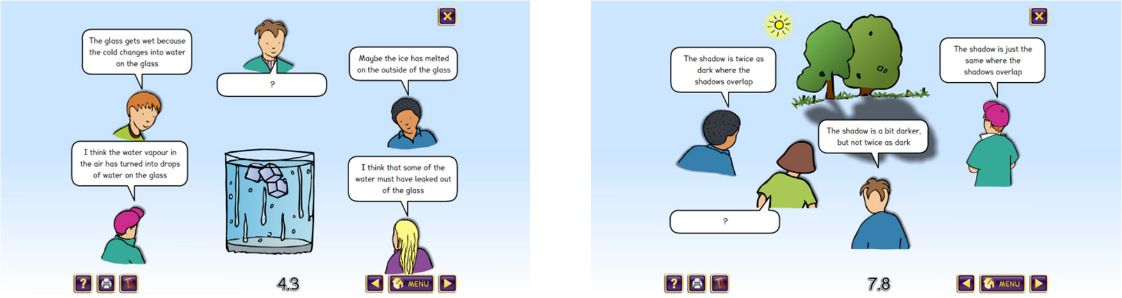
Key objectives of learning science are ***learning to reason with evidence* and *learning to reason with concepts and theories***. For a long time science curricula limited reasoning in elementary science curricula due to boundaries which had emerged from the work of Piaget. However recent studies have shown young children arguing well in advance of curriculum expectations (Tytler & Peterson, 2003). Young children may not be able yet to control variables, but they are capable of reasoning with evidence and concepts to some extent. The questions are what reasoning can they do potentially at their age and to what extent can this be achieved in typical classroom conditions?

Inquiry methods have been promoted for elementary science and technology education since the early 1960s (or even Dewey's time) and recently (Rocard et al., 2007) a strong plea for inquiry science was made at a European level. However, real implementation in the classroom is quite limited in most countries. Textbook science dominates and activities are more likely to be only hands-on than also minds-on. There is a need for inquiry teaching methods which have a lower threshold for teachers, which teachers are confident to start using and which still have the important key features of *reasoning with evidence* and *reasoning with concepts* and *recognizing and understanding different points of view.*

Exactly for that purpose Naylor and Keogh (1998, 1999) introduced first the concept cartoons and later the puppets (Simon et al., 2008). In concept cartoons characters hold incompatible views/claims about an everyday phenomenon. Children then are asked to argue about these claims using their own experiences as "evidence". This is what is mostly done in concept cartoon activities used around the world. **However, one could go one step further and ask children to design experiments to support or falsify statements in the cartoons. Then the cartoons in a very natural way lead to inquiry.**

Naylor et al. (2007) tried concept cartoons with children of age 8 and 9 and found that children were capable of supporting their views with arguments and listening and responding to arguments of others. An analysis scheme of arguments derived from Toulmin did not work, but a simple classification of interactions provided useful information. Children can argue about the cartoons based on their own everyday experiences, most children do use arguments and react to arguments of others and children co-construct arguments in their small groups without teacher support. However, also 18-year olds react well to concept cartoons as Naylor & Keogh point out in their 2012 review of concept cartoon studies.

Although there are many reports of teachers and researchers using concept cartoons to get students to design investigations, we have not yet found research reports except for our own (Berg et al., 2012). This workshop paper is intended to provide practical suggestions for how to use the cartoons to get students and teachers into investigations, based on our experiences in different schools and at different levels (grades 4–6). Some background knowledge on concept cartoons is assumed.



a) b)

Figure 1: a) Condensation, b) Shadows

PREPARATION FOR THE TEACHER

1. Choose a cartoon which provides sufficient possibilities for experimenting. Not all cartoons are appropriate. Identify the basic concepts and expected preconceptions and do a little bit of exploring the phenomenon in the cartoon.

   > The condensation cartoon (Figure 1a and see appendix for bigger version) always works very well. The cartoon about whether two overlapping shadows from the same light source are darker or not, did not lead to much creativity. On the other hand, a cartoon we made about skate boards getting off inclined planes spawned a great variety of experiments.

2. Think of some experimental ideas students might come up with and which materials might be needed for that.
3. Always have some extra materials as students might come up with unexpected ideas and we like to stimulate their creativity.
4. What are the key concepts and what are the main process skills you will pay attention while the students are at work? Is it reasoning with evidence, or will you focus on correct measurement this time, or on properly describing design/results/conclusions? In an investigation all of these will occur, but not all can be singled out for special attention. Prioritize and create a learning trajectory across the school year.

5. Make a list of questions the teacher can ask about the concepts and about the experiments. Some questions will be used by the teacher in plenary discussion before and after the activity, other questions will be used while the students are at work and the teacher goes around observing and reacting to the students' work.

THE LESSON

6. *Whole class.* Getting acquainted with the phenomenon

> Condensation example (appendix): put a glass of cold water from the refrigerator on the table and add some ice cubes. Let children observe, what happens? Do they see the water on the outside? Have they seen something like that before? Are there related experiences (car windows getting foggy, windows when taking a shower)? What are their experiences?

7. *Children individually.* Present the cartoon and let children answer individually on a worksheet whom they agree with and why. See example worksheet in the appendix.
8. *Whole class.* Make an inventory of the different opinions, experiences, and arguments. The teacher leads the discussion and assists students to present their ideas and explanations but remains neutral. The discussion ends with a list of questions which can be asked about the phenomenon.
9. *In small groups.* Divide the students in groups and (if the teacher chooses to) assign roles for cooperative learning. Ask children to think about experiments which can help them to find answers to one of the questions or to further investigate the statements in the cartoon. Let them describe the experiment briefly on the group worksheet (appendix).
10. Some groups have a tendency to right away start experimenting with the first idea that comes up. Try to get them to think a bit deeper about the experiment they propose. Let them fill in the worksheet (appendix) and question them critically. We ourselves usually postpone the actual experiments to the next lesson. There are two reasons for this: 1) we want the students to think deeper about what they are going to do, 2) students can list what equipment/materials they need and bring that to class next time. With some cartoons, for example those about falling motion, it is not feasible to postpone the actual experiments but with most cartoons the split in a preparation lesson and an experimental lesson works quite well.

> Grade 5: With a cartoon on bungee jumping in which the characters wondered whether heavy people would fall faster and farther, the children thought of building towers of lego or blocks, using rubber bands of equal lengths, and comparing a full water bottle (heavy person) with a half filled bottle (light person). Then they were going to do a fair comparison. One girl emphasized that the rubber bands for the heavy and the light bottle should be exactly equal length.

11. *Next lesson in small groups:* students carry out their experiments.
12. *In groups.* In elementary school the children probably have little experience in describing the set-up and results of their experiments. A worksheet helps to

give structure. Michael Klentschy (2008) developed a notebook method where children from 6–14 develop their skills in documenting their reasoning from expectation to observation and conclusion. His book shows nice examples of progression across the ages and this method has positive results both for science and language skills of students.

13. *Whole class.* Presentation of results during which other students and the teacher can ask critical questions. The two leading questions are: a) what have we learned about the phenomenon (e.g. condensation) and what is our evidence for that? And b) what did we learn about experimenting and doing research? To let all groups make oral presentations can be too time-consuming unless the teacher wants to practice oral presentation skills. Instead the teacher can lead a discussion about the two main questions in which the students introduce their evidence and reasoning.
14. Assist the class in the interpretation of research results after all groups have presented and then link back to the preconceptions at the start and point out what the class has now learned from the experiments. And certainly some new questions will come up.

EXPERIENCES AND SOLVING PROBLEMS WHEN TEACHING WITH CONCEPT CARTOONS

The try-out of concept cartoons generates a lot of enthusiasm and is usually successful. However, we also ran into problems for which we constructed solutions which have been tested in the classroom. The following points show both problems and solutions.

Designing experiments. Children are creative in thinking of experiments. When there are more variables, children have trouble to limit themselves to manipulate only one of these variables.

> When we asked how the melting of ice could be accelerated, they wanted to change everything to get the fastest melting while we wanted them to investigate the variables one by one. With some clever guidance this can be solved.

Quite frequently the research question and the proposed experiment do not fit.

> With the condensation cartoon one group claimed that water vapor from the air would condense on the outside of the glass. However, in their experiment they proposed to fill their glass with coca cola. So as if they wanted to investigate whether condensation also happens with other liquids than water.

If you do investigate this, it turns out that every liquid will work as long as the temperature is lower than that of the air. Water and water-based liquids such as Coca-Cola do particularly well as the specific heat of water is high and it takes a long time before the liquid reaches room temperature.

Predicting with reasons. Children can predict quite well but they cannot formulate their reasons well on paper and it helps if the teacher questions them and looks critically at their formulations. Obviously the skill of predicting and supporting the prediction with reasons requires a long learning trajectory.

Classroom management and cooperative learning. We usually use groups of 3. In every group one student is responsible for any communication with the teacher, one takes care of the equipment, and a third is responsible for good reporting. This prevents the problem that 30 children would line up for assistance of the teacher. In the next activity children get assigned to a different role. The roles are based on the Australian Primary Connections program (2008).

Designing en executing experiments. Children think of an experiment and too quickly get on with it. This can be prevented by doing the designing in one shorter lesson and the executing and reporting in the next and longer lesson. However, in the design lesson it is helpful to have some of the experimental materials in the room to help children in thinking about the design of their experiments. With the cartoon about falling motion, it will be difficult to stop children from trying out immediately, but do force them to think about what they are doing.

Executing experiments (1): Some children are busy reasoning and then conduct their experiment only once. Others go through many repetitions. With questions like *"How can you be sure of your results?"* you can let children think about the power of their experimental proof and how this could be enhanced by repetition or varying conditions.

Executing experiments (2): During the experiment children often change so many things that their experimental set-up no longer matches with the research question they started with. Of course there will be (and should be) improvements as they get more experience with their experiment, but they should not forget their main research question. The set-up of the worksheet (appendix) helps with that.

Final presentation: Groups of 4th grade children right away applauded their class mates when presenting instead of having a critical discussion. Solution: let children from the audience give a *'tip'* and a *'top'*. The *tip* is a suggestion for improvement. The *top* is about something the presenting group has done well. Even better is to let the audience indicate what they learned from the presentation that they did not know before. Of course one could also opt not to have final presentations by the groups but instead to have a post-lab discussion where all can contribute and the teacher keeps a clear focus.

In the post-lab discussion there are two central questions: a) *What did the group learn about the phenomenon and the major concepts?* and b) *what did the group learn about investigation/research.* At the end of the discussion, the teacher summarizes the answers to these two questions.

Worksheet or notebook: Carefully choose priorities for written reporting.

> In one group with selected talented grade 4 students we had a very ambitious worksheet where children had to predict, provide arguments, reason with those arguments and answer other questions about the experiment they were going to do. Our elaborate worksheet killed the motivation.

So carefully select priorities and keep the writing limited as in the example worksheet.

To conclude an interesting experience:

> Four talented grade 4 children (age 10–11) experimented with condensation (see cartoon in the appendix).Their first hypothesis was that the outside of the glass could only get wet inside the refrigerator. But in their first experiment with a glass that was dried on the outside, water

> still formed. Their second hypothesis was that the condensation water would come out of the glass. They put on a lid and predicted the outside would remain dry. However, it still became wet. They went through a series of experiments and discussions of everyday experience with windows fogging up. They observed that with hot water in the glass, the inside would get foggy. I demonstrated to them that my breath also creates water on the outside of a glass filled with water of room temperature. Then Emma made the big jump. She said that water vapor will form liquid water when it hits a colder surface. When asked how to test this, she suggested that if the water temperature in the glass would be above 37 degrees, then our breath would not form water on the glass. And she was right!

REFERENCES

Chin, C. & Teou, L. Y. (2009). Using concept cartoons in formative assessment: Scaffolding students' argumentation. *International Journal of Science Education*, 10(1), 1307–1332.

Keogh, B. & Naylor, S. (1998). Teaching and learning in science using concept cartoons. *Primary Science Review*, 51, 14–16.

Keogh, B. & Naylor, S. (1999). Concept cartoons, teaching and learning in science: an evaluation. *International Journal of Science Education*, 21(4), 431–446.

Keogh, B. & Naylor, S. (2012). *Concept cartoons, what have we learnt?* Paper presented at the Fibonacci Conference, Leicester, 26–27 April 2012. Available at http://www.millgatehouse.co.uk/research/concept-cartoons-research-ongoing

Klentschy, M. P. (2008). *Using science notebooks in elementary classrooms.* Washington: NSTA Press.

Naylor, S. & Keogh, B. (2000). *Concept cartoons in science education.* Sandbach, UK: Millgate House.

Naylor, S., Keogh, B. & Downing, B. (2007). Argumentation and primary science. *Research in Science Education*, 37, 17–39.

Primary Connections. (2008). *Science Teacher Guides for Age 4–12.* Canberra: Australian Academy of Science.

Rocard, M. et al. (2007). *Science education now: a renewed pedagogy for the future of Europe.* Brussels: European Commission Directorate-General for Research.

Simon, S., Naylor, S., Keogh, B., Maloney, J. & Downing, B. (2008). Puppets promoting engagement and talk in science. *International Journal of Science Education*, 30(9), 1229–1248.

Tytler, R. & Peterson, S. (2003). Tracing young children's scientific reasoning. *Research in Science Education*, 33, 433–465.

van den Berg, E., Kruit, P. & Wu, F. (2012). *Getting children to design experiments through concept cartoons.* In *Bridging the gap between education research and practice.* Available at http://www.fibonacci-project.eu/resources/events/leicester-conference-2012.html

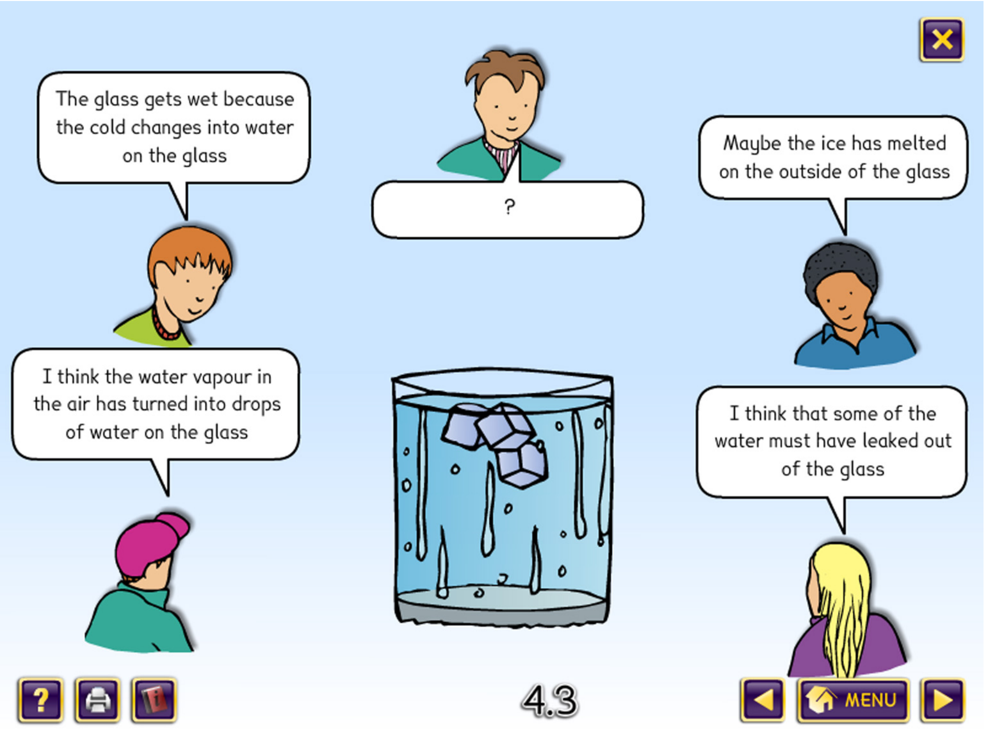
Appendix: Example worksheets ICPE Prague August 2013

Wet Glasses

Worksheet 1 Individual

Name: ____

A glass of water from the refrigerator with some ice cubes is put on the table. The outside of the glass becomes wet.



1) Who do you agree with? Why do you think so?

2) Could it be that one of the others is right? Explain.

Workheet 2 Group

With your group think of an experiment to further investigate the phenomenon in the cartoon or to collect evidence for or against one of the statements in the cartoon.

What is your research question?

What do you expect as an answer?

How are you going to do the experiment? (make a sketch)

What do you think will happen?

What do you need for the experiment?

How will you record the observations/measurements?

Worksheet 3: Group or individual

Remember, what did you expect?

What did you measure or observe?

How is that different from what you expected?

How do you explain what happened?

Ed van den Berg
Patricia Kruit
Vrije Universiteit Amsterdam and Hogeschool van Amsterdam

Scientia in educatione 8(Special Issue), 2017
p. 139–150
ISSN 1804-7106

Contextual Categorisation of Academics' Conceptions of Teaching

Scott Daniel, Alex Mazzolini, Llewellyn Mann

Abstract

Background: Despite large-class research-based instructional strategies being firmly established in the literature, traditional teacher-centred lecturing remains the norm. This is particularly the case in physics, where Physics Education Research (PER) has blossomed as a discipline in its own right over the last few decades, but research-based strategies are not widely implemented.

This variation in practice is underpinned by variations in beliefs and understandings about teaching. Studies investigating the spectrum of conceptions of teaching held by teachers and, in particular, academics have almost uniformly identified a single dimension from teacher-centred to student-centred. These studies have used a phenomenographic approach to capture the variety of conceptions of teaching, but have excluded contextual issues like class size.

Research Question: How does class size affect academics' conceptions of teaching?

Method: This study used an online survey to compare and contrast respondents' experiences of small and large classes, and in particular lectures. The survey was promoted to Australian university academics from a range of disciplines, predominantly science, technology, engineering, and mathematics (STEM). Responses to the sets of small-class questions were analysed independently from the sets of equivalent large-class questions. For each respondent their small-class responses were categorised, where possible, as either being student-centred or teacher-centred, and likewise, independently, for their large-class responses.

Results: In total, 107 survey responses were received. Of these, 51 had the sets of both their large- and small-class responses unambiguously categorised. Five of these were student-centred regardless of class size, and 17 of these were teacher-centred regardless of class size. All of the remaining 29 responses were teacher-centred in large classes, but student-centred in small classes. Conversely, none of the responses corresponded to a conception of teaching that was student-centred in large classes and teacher-centred in small classes.

Implications: This result demonstrates that the one-dimensional analysis of conceptions of teaching along the spectrum of teacher-centred to student-centred is too simplistic. Conceptions are contextual. At the very least they depend on class size, and perhaps other factors.

It confirms the hierarchy of understanding from teacher-centred to student-centred reported elsewhere in the literature, with the added feature of an intermediate stage of differing focus depending on class size. One recommendation from this finding is that teaching professional development programs should be focused on developing student-centred conceptions and practices in large classes in particular, as this occurs infrequently but leads to the best student learning outcomes. Moreover, further research on context-specific conceptions of teaching need to be explored.

Key words: conceptions of teaching, context, professional development, phenomenography.

INTRODUCTION

CONCEPTIONS OF TEACHING

A number of studies have explored the variation in teachers' conceptions of teaching. Kember (1997) reviewed 13 such studies and identified a common thread: they all categorised conceptions of teaching along a single dimension anchored at one end with "teacher-centred/content-oriented" conceptions, and at the other with "student-centred/learning-oriented" conceptions (see Table 1 below, adapted directly from Kember (1997: p. 262). Although the various studies Kember reviewed differed in how they divided up this continuum into a hierarchy of discrete categories, the opposite poles of teacher-centred/content-oriented and student-centred/learning-oriented were common to all. (In the remainder of this paper the terms "teacher-centred" and "student-centred" will be used as shorthand).

Table 1: Kember's characterisation of the extremes of the continuum of teachers' conceptions of teaching

Aspect	Teacher-centred extreme	Student-centred extreme
Teacher	Presenter	Change agent/developer
Teaching	Transfer of information	Development of person and conceptions
Student	Passive recipient	Lecturer responsible for student development
Content	Defined by curriculum	Constructed by students but conceptions can be changed
Knowledge	Possessed by lecturer	Socially constructed

The studies which Kember reviewed showed a high degree of commonality in identifying this continuum from teacher-centred to student-centred conceptions. This is even the more striking when the diversity of the different studies' participants is considered. In total, almost 500 educators (university academics and adult educators) participated. A wide range of disciplines (e.g. physics, social sciences, English, medicine), countries (e.g. Australia, China, Singapore, USA), and experience levels (from new lecturers to award-winning university teachers) were represented. This finding has also been borne out in subsequent studies (Postareff & Lindblom-Ylänne, 2008; Samuelowicz & Bain, 2001). Trigwell and Prosser (1996) developed a survey instrument (the Approaches to Teaching Inventory, or ATI) using items based on this continuum of conceptions and subsequently refined and validated it with more than 2000 university teachers from a range of disciplines, countries, and experience levels (Trigwell & Prosser, 2004, 2006; Trigwell, Prosser & Ginns, 2005).

However, in the ATI, and the other studies, the focus was respondents' conceptions of teaching, without regard to how this may vary with respect to contextual factors, such as class size. This then is the focus of this paper: how does class size affect academics' conceptions of teaching? And why is this question important?

Conceptions of teaching underpin teaching and learning practice

Conceptions of teaching matter. They underpin what academics do as teachers, and affect how students learn. Trigwell and Prosser (1996) found that academics who hold teacher-centred conceptions employ teacher-centred strategies, and likewise for those academics with student-centred conceptions. (Although at least one study has contested this (Murray & Macdonald, 1997)).

Furthermore, in a study of almost 4 000 students, it was found that students of teachers who describe teacher-centred conceptions adopt shallow approaches to learning, whereas students of teachers who report student-centred conceptions have deeper approaches to their learning (Trigwell, Prosser & Waterhouse, 1997).

Student-centred teaching practices lead to better student outcomes

Student-centred strategies lead to better student outcomes. This has been shown in a number of studies in a range of contexts. Hake (1998) published a seminal study of more than 6 000 physics students and found that what he called "interactive-engagement" (student-centred) strategies consistently resulted in greater gains in student conceptual understanding than "traditional" (i.e. teacher-centred) instruction.

Similar results have been found across a range of disciplines (Prince, 2004; Masikunas, Panayiotidis & Burke, 2007; FitzPatrick, Finn & Campisi, 2011) and countries (Abdul et al., 2011; Hussain, Azeem & Shakoor, 2011; Cahyadi, 2004). Student-centred strategies also lead to better student attendance and engagement (Deslauriers, Schelew & Wieman, 2011).

Professional development is ineffective if it ignores participants' teaching conceptions

Henderson and Beach (2011) reviewed several hundred articles from 1995–2008 reporting on different initiatives to reform undergraduate instruction in science, technology, engineering, and mathematics. They identified a number of factors common to successful, and unsuccessful, reforms. Change strategies that do not acknowledge the beliefs of the participants are ineffective. Conversely, those that align with or are deliberately designed to change teachers' conceptions (Ho, Watkins & Kelly, 2001) can be very successful.

Motivation for this study

This study is part of a larger project that aims to understand why traditional, teacher-centred instruction remains the norm (Nunn, 1996; Skovsmose, Valero & Christensen, 2009), especially in lectures, when the evidence against its educational effectiveness seems so compelling. In the authors' view, the primary goal of professional development should be to improve learning outcomes for students. In order to do so, it must address academics' conceptions of teaching. Although teaching conceptions are understood in general terms, this study sought to identify whether academics' conceptions of teaching are dependent upon class size in any way. This paper will attempt to answer this question, and then conclude with some conjectures about what this might mean for professional development programs.

Methodology

This project builds on the phenomenographic research literature about conceptions of teaching. Phenomenography assumes that different people conceive of or experience the same phenomenon in a small number of qualitatively distinct ways (Marton, 1981).

It is not assumed that any phenomenographic study will absolutely and unambiguously identify the complete conceptions held by the particular individual participants about the phenomenon in question; rather it is acknowledged that the data collected is just a partial snapshot of their views at the particular time of the study, further filtered through the context of how the data was collected.

In this study, the different contexts of small and large classes were deliberately highlighted to draw out any contrasts in how participants may conceive of teaching in these different settings.

Data was collected using an online survey. Although online surveys are static and coarse compared to the more richly detailed information generated by interviews, more typical of phenomenographic research, it did facilitate recruitment of participants from diverse disciplines and geographic locations. Through the survey, participants for follow-up interviews were recruited. These follow-up interviews explore participants' conceptions of teaching in more depth, and are the subject of other publications (Daniel, 2016; Daniel, Mann et al., 2016).

Using an online survey also made it easy to discriminate between respondents' conceptions of teaching small classes versus large classes, because questions about the two contexts could be worded identically. Such transparent even-handedness is difficult to achieve in interviews, where unintended biases in how questions are posed can affect how participants respond. To address the research question of this paper, how respondents answered the set of small class questions was compared and contrasted with how they answered the set of large class questions.

Survey Design

A survey instrument was designed in Survey Monkey^{TM} to explore academics' conceptions of teaching small classes, large classes, and, in particular, lectures. It was promoted to university academics at an Australian university through staff emails and newsletters.

The original survey was constructed by the authors in consultation with a professional form designer. It was then piloted with 6 respondents and reviewed in detail to identify any ambiguous wordings, confusing question sequences, or other issues (Fowler & Jackson, 1992).

The survey consisted of several sections. The first, which will be explored in detail in this paper, was designed to compare and contrast academics' experiences of large versus small classes. The second section focused on academics' experiences of lecturing. The third and final section focused on relevant demographic information.

The first section, designed to contrast small and large classes, had 4 parts, each with a different theme:

- Class size & word associations
- The academic's enjoyment
- The academic's confidence
- Student engagement

In the first part respondents were asked to numerically characterise what they meant by a small and large class (i.e. what is the maximum size of a 'small' class, and the minimum size of a 'large' class), and to generate up to five words or phrases that they associated with large and small classes respectively.

The next three parts, focusing on enjoyment, confidence, and engagement, all had a similar design. In the part focused on enjoyment, respondents could use a Likert-scale to identify to what extent they agreed with the statement that they enjoyed teaching large classes, and why, and then likewise for small classes. The following two parts substituted statements about confidence in teaching, and student engagement, but otherwise followed the same layout.

The importance of reducing response bias and minimising respondent burden was paramount (Bradburn, 1978; Choi & Pak, 2005).

For example, two factors affecting how respondents answer multiple-choice or Likert-scale questions are primacy (the first response is favoured) and social acquiescence (respondents want to agree with the perceived views of the researcher) (Schuman & Presser, 1996; King & Leigh, 2009). These biases can be offset against one another by ranking the Likert-scale from 'strongly disagree' to 'strongly agree'. The primacy effect favours the response listed first (i.e. 'strongly disagree'), whereas the social acquiescence bias instead typically favours 'strongly agree'.

Although 5-point Likert-scales are frequently used (Clason & Dormody, 1994), in this study a 7-point scale was chosen. Although this adds somewhat to the respondent burden, and may therefore lead to satisficing (i.e. choosing the minimally adequate, often just neutral, response (Krosnick, 1991; Krosnick et al., 2002), it was deemed necessary for this study. This was because the scale had not only to differentiate between agree and disagree, but also to discriminate between the intensity of responses to the same statement for small versus large classes. For example, knowing that a particular respondent is confident teaching both large and small classes is not that informative about the differences between these two contexts. By using a 7-point scale (that is, with 3 levels of 'agreement', and 3 levels of 'disagreement'), the contrasting experience between small and large classes could be highlighted.

Context plays a key role in survey design (Schwarz & Sudman, 1992). For this study that meant that it was important to have the pairs of identical questions about large and small classes together in each part, to make it clear that a comparison was intended. Also, each part focused on one particular aspect of the teaching experience (e.g. confidence, enjoyment), and this theme was highlighted at the top of each part to make the focus clear.

Other factors that were important in the survey's design were simplicity of language and the anonymity of respondents. For example, after each Likert-scale response identifying to what extent respondents disagreed or agreed with a statement, they were simply asked "Why is that?" Through an iterative review process between the authors, the professional form designer, and the pilot survey respondents, the questions were revised until they were as simple and clear as possible.

Finally, survey responses were anonymous. This is not only ethically sound but minimises the social desirability bias in which respondents are less likely to report socially undesirable beliefs or behaviours (e.g. lacking confidence, or thinking students are not engaged in their classes).

DATA ANALYSIS OF QUESTIONS ABOUT SMALL AND LARGE CLASSES

The survey received 107 responses from a range of disciplines across the university. The sets of responses to only the small class questions were analysed independently of an equivalent analysis of the sets of responses to only the large class questions. These sets of responses (corresponding to one individual respondent) were categorised as being at either extreme of Kember's spectrum: that is, either teacher-centred/content-oriented, or student-centred/learning-oriented. However, some responses, either through their sparseness or the possibility of different interpretations, were categorised as "ambiguous". This term is not used to suggest that the respondents' conceptions were unclear or contradictory, just that the survey instrument was too coarse to discriminate subtleties in their ideas, and only the categorisation of more polarised views could be justified.

In Table 2 some representative responses are shown, and how they were categorised. The set of responses categorised as "ambiguous" came from one respondent, and were categorised as such because they could be interpreted in either a teacher-centred or student-centred way. For example, the teacher could be an animated presenter [dynamic], who's very active at the front of the class [activities], and the students are watching [engagement]. Alternatively, it could be that there is a lot of interaction between the student and teacher [dynamic], the students are doing a variety of different tasks [activities], and the students are very involved [engagement]. Where it was possible to interpret the set of responses in different ways, they were classified as "ambiguous".

Table 2: The categorisation of some sample quotes

Teacher-centred	**Ambiguous**	**Student-centred**
Performance	Dynamic	Individual questions
Keeping [students'] attention	Lots of marking	Knowing [students'] names
Useful information	Activities	Peer learning
Content-driven	Engagement	Interaction
Getting the message across		Personal
		Depth of learning

RESULTS

The respondents clearly had different views of large and small classes. In Figures 1 and 2 below, word clouds (Steinbock, 2006) have been generated from the total set of responses to the large class questions, and separately to the small class questions. In these word clouds, words are listed in alphabetical order, with a size proportional to how frequently they occurred in the text.

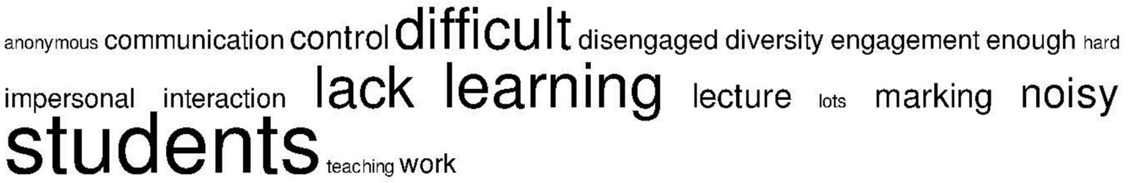


Figure 1: Common words in the large class responses

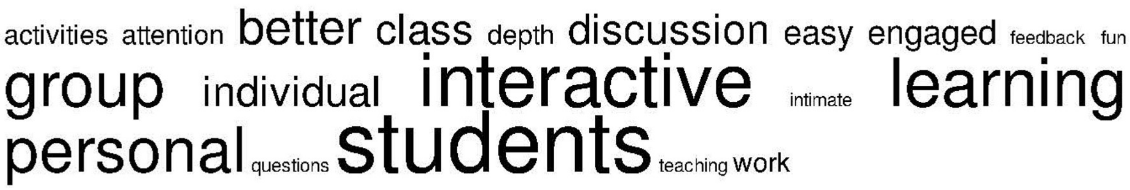


Figure 2: Common words in the small class responses

The connotations of the most common words in the large class responses were quite negative (e.g. “lack”, “difficult”, “noisy”) compared to those for the small classes (e.g. “easy”, “better”, “engaged”). Although this is an interesting difference, it is difficult to draw insightful conclusions because it is only a comparison of word frequency, without regard to what sense, or in what context, these words were used.

Responses to the large class and small class questions were then categorised more meaningfully as either teacher-centred or student-centred (see Table 3 below). Some responses could not be categorised unambiguously because they could be interpreted in multiple ways. These responses have been shaded in Table 3.

Table 3: Categorisation of responses by class size

$N = 107$		**SMALL CLASSES**		
		Teacher-centred	**Ambiguous**	**Student-centred**
LARGE CLASSES	**Teacher-centred**	17	34	29
	Ambiguous	0	13	9
	Student-centred	0	0	5

Taking out the “ambiguous” responses to leave only the responses that were categorised unequivocally gives the distribution shown in Table 4 ($N = 51$).

Table 4: Subset of unequivocally categorised responses by class size

$N = 51$		**SMALL CLASSES**	
		Teacher-centred	**Student-centred**
LARGE CLASSES	**Teacher-centred**	17 (33 %)	29 (57 %)
	Student-centred	–	5 (10 %)

Discussion

These results raise some interesting questions. For example, what is it to be teacher-centred in a large class but student-centred in a small class?

In large classes, teacher-centred instruction could for example simply be the traditional lecture: the sage on the stage (Horton, 2001), whereas student-centred instruction might look more like Peer Instruction (Mazur, 1997): the guide on the side.

Similarly in small classes, teacher-centred instruction could take the form of 'chalk and talk' tutorials where the tutor works through a problem on the board, whereas student-centred instruction could include small group problem-solving sessions, for example.

In Table 5 below, the different quadrants have been characterised by these corresponding representative teaching strategies. As a shorthand, these quadrants have been labelled A, B, and C. Note that the bottom-left quadrant has not been labelled, as not one of the 107 survey respondents demonstrated teacher-centred conceptions in small classes, coupled with student-centred conceptions in large classes. Only the converse was observed. On the spectrum between wholly teacher-centred conceptions and wholly student-centred conceptions there seems to be only one intermediate: teacher-centred conceptions in large classes coupled with student-centred conceptions in small classes.

Table 5: Sample characterisation of different categories of responses

		SMALL CLASSES	
		Teacher-centred	**Student-centred**
LARGE CLASSES	**Teacher-centred**	Traditional lectures: the sage on the stage Chalk and talk tutorials: Tutor solves problems on board A	Traditional lectures: the sage on the stage Problem-solving in small groups B
	Student-centred	Peer instruction in lectures: the guide on the side Chalk and talk tutorials: Tutor solves problems on board	Peer instruction in lectures: the guide on the side Problem-solving in small groups C

The weight of evidence summarised earlier in the introduction (Hake, 1998; Prince, 2004; Masikunas, Panayiotidis & Burke, 2007; FitzPatrick, Finn & Campisi, 2011; Abdul et al., 2011; Hussain, Azeem & Shakoor, 2011; Cahyadi, 2004; Deslauriers, Schelew & Wieman, 2011) shows that student-centred strategies, in both large and small classes (labelled quadrant C in the table), lead to the best student learning outcomes. In the authors' view, shifting academics' conceptions and practice towards this should be the goal of professional development programs. But how best to affect this transition: for example, should there be programs targeted at the A → B transition (i.e. for academics with teacher-centred conceptions of teaching, first developing student-centred conceptions and practice only in small classes), and then other programs separately targeting the transition B → C (extending small class student-centred conceptions to a context of larger classes)? And is it even possible for individuals' conceptions of teaching to change, or be changed, in this way?

Academics' conceptions of teaching, just like student conceptions of different phenomena, can change (McKenzie, 2003). In fact many successful professional development programs have sought to do just that (Henderson, Beach & Finkelstein, 2011; Ho, Watkins & Kelly, 2001). However, academics advance through these conceptions at different rates (Martin and Ramsden (1992), cit. in Kember (1997)), and it certainly seems unlikely that each transition would be equally easy (Kember, 1997). So perhaps there is some conceptual 'bottleneck', a breakthrough that is difficult to make.

The best candidate from this study is the transition B → C, the development from teacher-centred to student-centred conceptions in large classes. To draw an analogy from chemistry, this could be the "rate-determining step", where academics progress relatively easily from A → B, but only a trickle makes the next step B → C, and so B is the biggest group and C the smallest. Furthermore, the academics with student-centred conceptions (Quadrant C) are probably over-represented in this study because arguably they would value teaching more highly and be more motivated to give up their time to participate in the study in the first place. This self-selection bias means that the proportion of academics holding wholly student-centred conceptions of teaching is probably in fact even smaller, which further reinforces the conjecture that the transition B → C is a conceptual bottleneck.

If these transitions between groups happened uniformly, the groups should reflect increases in experience levels. However, this isn't apparent in the demographic data for the three groups, which each have at least 40 % of respondents reporting more than 10 years' of academic experience and respondents' "highest qualifications" ranging from undergraduate to doctoral. It is probably too simplistic to expect conceptual development to run to a timetable, when in fact it is the quality, not quantity, of experiences and critical incidents that drive conceptual change.

So if the transition B → C, the development from teacher-centred to student-centred conceptions in large classes, is indeed the conceptual bottleneck the relative sizes of the groups suggest it is, it makes sense to focus professional development programs on enabling that change.

Alternatively, it could be argued that supporting step-wise development would be the most effective. That is, if academics with teacher-centred conceptions regardless of class size (Quadrant A in the table above) could be brought together to focus on developing student-centred conceptions and practice in small classes (i.e. the transition A → B), it would likely be successful as this seems to be a small conceptual shift. Likewise, if academics from Quadrant B (with student-centred views in small classes but teacher-centred views in large classes) could be brought together and supported to develop student-centred conceptions and practice in large classes (i.e. B → C), for these academics this is a small step. And therefore academics with student-centred views regardless of class size (Quadrant C), whose views align with the evidence about best practice, could perhaps be ignored.

However, the outcome of the phenomenographic research (Kember, 1997; Postareff & Lindblom-Ylänne, 2008; Samuelowicz & Bain, 2001; Trigwell & Prosser, 1996, 2004, 2006; Trigwell, Prosser & Ginns, 2005) that frames this study was not to unambiguously categorise participants' conceptions of teaching, rather the outcome was the set of conceptions themselves. To claim that individual participants' conceptions could be unequivocally identified in some absolute way is spurious. And even if they could be, to group academics by the perceived value of their ideas would certainly be perceived as condescending, if not insulting. So step-wise professional development programs targeted at groups of academics with different conceptions is impractical.

Instead, in the authors' view, professional development programs should be targeted at developing student-centred teaching conceptions and practice in large classes, for all academics. From the survey data, it seems this is a conceptual 'bottleneck' that relatively few academics navigate through. By treating all academics equally, it avoids alienating those academics with teacher-centred conceptions by implying that their ideas are of lesser value. Furthermore, it would support academics with student-centred conceptions (Quadrant C) translate these conceptions into practice. Although conceptions and practice generally align (Trigwell & Prosser, 1996), sometimes the practice lags the conception – that is, the conceptions are student-centred but the practice is more teacher-centred (Murray & Macdonald, 1997; Henderson, 2004).

This finding is based upon one analysis of the survey data. Further research and analysis is needed to explore these ideas in more detail. To that end, the survey data was also analysed in two other ways. On one hand, complete sets of responses (i.e. complete survey scripts) were categorised using a typical phenomenographic approach (Marton, 1981, 1986; Bowden & Walsh, 2000) into a spectrum from teacher-centred to student-centred conceptions. On the other hand, individual responses to individual questions were coded for various themes. These two extremes of global and local analysis will be the focus of future publications. In addition, some survey respondents nominated themselves for follow-up interviews, which allowed their ideas about teaching and learning to be explored in more depth (Daniel, 2016; Daniel, Mann et al., 2016).

Conclusion

Analysis of a survey of Australian academics' conceptions of teaching revealed that there seems to be a progression from teacher-centred conceptions, to student-centred conceptions only in a small-class context, to student-centred conceptions regardless of class size. Student-centred conceptions of teaching underpin student-centred practice, which leads to the best student learning outcomes. Professional development programs should be aimed at developing these student-centred conceptions and practice. It has been argued that these programs should be focused on developing student-centred conceptions and practice in large classes in particular, because this is a conceptual bottleneck that few academics navigate through.

References

Abdul, B. et al. (2011). Addressing student learning barriers in developing nations with a novel hands-on active pedagogy and miniaturized industrial process equipment: The case of Nigeria. *International Journal of Engineering Education*, 27(2), 458–476.

Bowden, J. A. & Walsh, E. (Eds.). (2000). *Phenomenography.* Melbourne: RMIT University Press.

Bradburn, N. M. (1978). Respondent burden. In *Proceedings of the American Statistical Association (Survey Research Methods Section)*, 35–40.

Cahyadi, V. (2004). The effect of interactive engagement teaching on student understanding of introductory physics at the faculty of engineering, University of Surabaya, Indonesia.*Higher Education Research & Development*, 23(4), 455–464.

Choi, B. C. K. & Pak, A. W. P. (2005). A catalog of biases in questionnaires. *Preventing chronic* disease, 2(1), 1–13.

Clason, D. L. & Dormody, T. J. (1994). Analyzing data measured by individual likert-type items. *Journal of Agricultural Education*, 35(4), 31–35.

Daniel, S. A. (2016). *Experiences of lecturing.* PhD, Swinburne University of Technology.

Daniel, S. A., Mann, L. M. W. & Mazzolini, A. P. (2016). A phenomenography of lecturing. *44th SEFI Conference.* Tampere, Finland.

Deslauriers, L., Schelew, E. & Wieman, C. (2011). Improved learning in a large-enrollment physics class. *Science*, 332(6031), 862–864.

FitzPatrick, K. A., Finn, K. E., & Campisi, J. (2011). Effect of personal response systems on student perception and academic performance in courses in a health sciences curriculum. *Advances in Physiology Education*, 35(3), 280–289.

Fowler, J. & Jackson, F. (1992). How unclear terms affect survey data. *Public Opinion Quarterly*, 56(2), 218–231.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74.

Henderson, C. (2004). Easier said than done: A case study of instructional change under the best of circumstances. In *Proceedings of the 2003 Physics Education Research Conference, Madison, Wisconsin.* New York: American Institute of Physics.

Henderson, C., Beach, A. & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, 48, 952–984.

Ho, A., Watkins, D. & Kelly, M. (2001). The conceptual change approach to improving teaching and learning: An evaluation of a Hong Kong staff development programme. *Higher Education*, 42(2), 143–169.

Horton, B. W. (2001). Shifting from the sage on stage to the guide on the side: the impact on student learning and course evaluations. *Journal of Hospitality & Tourism Education*, 13(5), 26–34.

Hussain, A., Azeem, M. & Shakoor, A. (2011). Physics teaching methods: scientific inquiry vs traditional lecture. *International Journal of Humanities and Social Science*, 1(19), 269–276.

Kember, D. (1997). A reconceptualisation of the research into university academics' conceptions of teaching. *Learning and Instruction*, 7(3), 255–275.

King, A. & Leigh, A. (2009). Are ballot order effects heterogeneous? *Social Science Quarterly*, 90(1), 71–87.

Krosnick, J. A. (1991). Response strategies for coping with the cognitive demands of attitude measures in surveys. *Applied Cognitive Psychology*, 5(3), 213–236.

Krosnick, J. A. et al. (2002). The impact of 'no opinion' response options on data quality: Non-attitude reduction or an invitation to satisfice? *Public Opinion Quarterly*, 66(3), 371–403.

Marton, F. (1981). Phenomenography — Describing conceptions of the world around us. *Instructional Science*, 10(2), 177–200.

Marton, F. (1986). Phenomenography — A Research approach to investigating different understandings of reality. *Journal of Thought*, 21(3), 28–49.

Masikunas, G., Panayiotidis, A. & Burke, L. (2007). The use of electronic voting systems in lectures within business and marketing: a case study of their impact on student learning. *Research in Learning Technology*, 15(1), 3–20.

Mazur, E. (1997). *Peer instruction: a user's manual.* Upper Saddle River: Prentice Hall.

McKenzie, J. A. (2003). *Variation and change in university teachers' ways of experiencing teaching.* Sydney: University of Technology.

Murray, K. & Macdonald, R. (1997). The disjunction between lecturers' conceptions of teaching and their claimed educational practice. *Higher Education*, 33(3), 331–349.

Nunn, C. E. (1996). Discussion in the college classroom: Triangulating observational and survey results. *Journal of Higher Education*, 67(3), 243–266.

Postareff, L. & Lindblom-Ylänne, S. (2008). Variation in teachers' descriptions of teaching: Broadening the understanding of teaching in higher education. *Learning and Instruction*, 18(2), 109–120.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223–231.

Prosser, M. & Trigwell, K. (2006). Confirmatory factor analysis of the approaches to teaching inventory. *Br J Educ Psychol*, 76(2), 405–419.

Samuelowicz, K. & Bain, J. D. (2001). Revisiting academics' beliefs about teaching and learning. *Higher Education*, 41(3), 299–325.

Schuman, H. & Presser, S. (1996). *Questions and answers in attitude surveys: experiments on question form, wording, and context.* New York: Academic Press.

Schwarz, N. & Sudman, S. (Eds.). (1992). *Context effects in social and psychological research.* New York: Springer-Verlag.

Skovsmose, O., Valero, P.& Christensen, O. (Eds.). (2009). *University science and mathematics education in transition.* New York: Springer.

Steinbock, D. (2006). *Tag Crowd.* Available at http://tagcrowd.com/

Trigwell, K. & Prosser, M. (1996). Congruence between intention and strategy in university science teachers' approaches to teaching. *Higher Education*, 32(1), 77–87.

Trigwell, K. & Prosser, M. (2004). Development and use of the approaches to teaching inventory. *Educational Psychology Review*, 16(4), 409–424.

Trigwell, K., Prosser, M. & Ginns, P. (2005). Phenomenographic pedagogy and a revised approaches to teaching inventory. *Higher Education Research & Development*, 24(4), 349–360.

Trigwell, K., Prosser, M. & Waterhouse, F. (1997). Relations between teachers' approaches to teaching and students' approaches to learning. *Higher Education*, 37(1), 57–70.

SCOTT DANIEL
ALEX MAZZOLINI
LLEWELLYN MANN
Swinburne University of Technology, Melbourne, Australia

sciED

Scientia in educatione 8(Special Issue), 2017
p. 151–164
ISSN 1804-7106

Quantitative and Qualitative Analysis of the Mental Models Deployed by Undergraduate Students in Explaining Thermally Activated Phenomena

Claudio Fazio, Onofrio Rosario Battaglia,
Rosa Maria Sperandeo-Mineo

Abstract

In this contribution we describe a research aimed at pointing out the quality of mental models undergraduate engineering students deploy when asked to create explanations for phenomena/processes and/or use a given model in the same context. Student responses to a specially designed written questionnaire are initially analyzed using researcher-generated categories of reasoning, based on the Physics Education Research literature on student understanding of the relevant physics content. The inferred students' mental models about the analyzed phenomena are categorized as practical, descriptive, or explanatory, based on an analysis of student responses to the questionnaire. A qualitative analysis of interviews conducted with students after the questionnaire administration is also used to deepen some aspects which emerged from the quantitative analysis and validate the results obtained.

Key words: mental models, quantitative data analysis.

INTRODUCTION

Among many cognitive theories, those explaining student reasoning in terms of structured cognitive conceptions, or mental models (Johnson-Laird, 1983), are of special interest for physics education. For this reason, many research papers (Bao & Redish, 2006; Maloney & Siegler, 1993; Carley & Palmquist, 1992; Corpuz & Rebello, 2011; Chittleborough & Treagust, 2007) studied students' understanding of models in different contexts, the mental models deployed by students in order to make sense of given phenomenology, and their *expressed forms* (Gilbert & Boulter, 1998), often using qualitative or quantitative analysis methods.

However, in the last years there has been a move in social science towards multi-method approaches, which tend to emphasize the breadth of information which the use of more than one analysis method may provide to the researcher (Tashakkori & Teddlie, 2003; Brewer & Hunter, 2006). Research results on eliciting and characterizing student mental models, based on the joint use of quantitative and qualitative methods, can be found in the literature (Hrepic, Zollman & Rebello, 2005; Bao, 1999). Our paper develops this research context and is mainly focused on the discussion of students' scientific explanations (Gilbert, Boulter & Rutherford, 1998) to an everyday life phenomenon, relating it to the physics and chemistry they have already studied in previous courses. The focus is on systems for which a process is thermally activated by overcoming a well-defined potential barrier, ΔE, and is therefore described by an equation containing the Boltzmann factor, $\exp(-\Delta E/KT)$, where T is the system temperature and K is the Boltzmann constant.

The method involves the construction of a tool (a specially designed open-answer questionnaire) and a quantitative analysis of student responses, supported by the qualitative analysis of specifically designed interviews. The questionnaire items are reported in the Appendix and are better discussed in (Fazio, Battaglia & Di Paola, 2013), where more detail on the whole research are reported and the related results are studied by using a quantitative method based on statistical implicative analysis, different from the one we present here. The study is performed by analyzing the expressed forms of the mental models student use when tackling a written questionnaire and interviews, i.e. their "answering strategies".

The results discussed here have been obtained with students of the 3-year Bachelor Degree Program in Chemical Engineering at the University of Palermo (UniPA), Italy. In the next sections we present the different steps of our research by explaining the research questions, methods and data analysis, and discuss our results.

THE RESEARCH

RESEARCH SAMPLE

Our research sample consists of 34 freshmen, enrolled in the Chemical Engineering Degree Program during the Academic Year 2010/2011 at UniPA. During the 1st semester of their Degree Program the students attended general mathematics, physics and inorganic chemistry courses, and they had already passed the related exams. When requested to participate in our study, they were attending a 2$^{\text{nd}}$ semester Physics course dealing with the fundamentals of electromagnetism, and voluntarily chose to participate in the survey. The total number of students on the course was about 60.

Research questions

Following the general theoretical framework and the research aims discussed above, this paper directly addresses the following research questions:

- What are the characteristics of the mental models students deploy when searching for explanations to phenomena/situations related to real-life and to subjects studied in previously attended courses?
- Do students highlight consistency in their deployment of mental models?

Methodology

The general lines used for this research are summarized in six "steps", that are shown below. More detail can be found in (Fazio, Battaglia & Di Paola, 2013).

Step 1: The questionnaire items (reported in the Appendix) are formulated on the basis of a review of Educational Research literature and a survey conducted with some UniPA university teachers.

Step 2: Validation of the questionnaire is performed: 5 physics freshmen, coming from the same secondary schools attended by our student sample, are asked to highlight problems in the questions, like unclear or ambiguous terminology. Then researchers make an independent analysis of the possible (*a-priori*) student responses to the questionnaire items, which results in the singling out of a set of possible answering strategies for each item (Brousseau, 1997).

Step 3: After the submission of the questionnaire to the research sample, researchers independently analyze actual student responses to each item and compare them with the a-priori found answering strategies, adding new ones as needed. The questionnaire items and the related student answering strategies are reported in the Appendix.

Step 4: It is assumed that each student has a latent cognitive structure underlying their answers to the questionnaire items, referred to as a "mental model". Answering strategies are grouped into idealized sets. Each set is synthesized by typical reasoning procedures that allow us to infer an epistemic category of students' mental models, defined as "practical/everyday", "descriptive", or "explicative".

Step 5: The extent to which actual student answering strategies correspond to the idealized categories is studied by using quantitative analysis methods (Gower, 1966; Mantegna, 1999).

Step 6: An interview protocol is designed by the researchers and interviews are taken with a subset of the student sample in order to extend and validate the results obtained by means of the quantitative analysis. The interviews are conducted immediately after the questionnaire submission, on a voluntary basis. The interview questions are aimed at supplying relevant information about the meaning of students' answers and at widening the analysis of their answering strategies, highlighting points of interest or unusual elements in the questionnaire answers. Checking the validity of the questionnaire items in actually revealing the students' reasoning when constructing explanations was another aim of the interviews. The interview protocol is pre-designed by all three researchers, but the interviews are conducted by one of them, face to face with the students. In many cases, questions not included in the interview protocol are asked, in order to better clarify specific situations which emerged during the discussion.

Questionnaire analysis

During the analysis of the student answering strategies, each researcher draw up a table summarizing them. Discordances between researchers' tables were found in some cases, when a student answer was classified under 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 researchers' interpretations of students' statements. This happened 19 times when comparing the tables of researchers 1 and 2, 17 times for researchers 1 and 3 and 16 times for researchers 2 and 3. Hence, a good inter-rater reliability of the analysis is demonstrated, with accordance percentages of about 91–92 % between the analysis tables of each pair of researchers. 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 to the questionnaire items, within a framework provided by domain-specific expertise and previous research in the field of the description of student modelling competencies (Sperandeo-Mineo, Fazio & Tarantino, 2006), allowed us to classify students' responses into three phenomenographic (Marton, 1988; Marton & Booth, 1997) categories of mental models. They are Practical/Everyday, Descriptive and Explicative, as described in Table 1, where the reasoning procedures representative of each model category are also shown.

Table 1: Categories of mental models deployed by students when tackling the questionnaire and the related reasoning procedures

Practical/Everyday	**Descriptive**	**Explicative**
Reflects the creation of situational meanings derived from practical, everyday contexts. The student uses other situations to try to explain the proposed situations.	*The student describes and characterizes the analyzed process by finding/remembering the relevant variables and/or recalling from memory their relations, expressing them by means of different language (verbal, iconic, mathematic). He/she does not explain the causal relations of the physics parameters involved on the basis of a functioning model (microscopic/macroscopic).*	*The student proposes a model (qualitative and/or quantitative) based on a cause/effect relation or provides an explanatory hypothesis by introducing models which can be seen at a theoretical level.*

We then built a table which identifies three 'idealized sets' containing the answering strategies that can be considered typical of each mental model category shown in Table 1. Each set defines the ideal profile of a student answering all the questionnaire items always using strategies related to the same category of mental model. These profiles have been used for a similarity analysis between them and the real students, as explained in the following. More detail can be found in (Fazio, Battaglia & Di Paola, 2013).

In order to study the “similarity” between the students and the three categories of mental models we identified in Step 4 of our analysis, we compared the answers given by the students with the answers typical of each ideal student profile, and calculated the Pearson’s correlation coefficients, r_{ij} between each students and the three profiles, where i $(i = 1, 2, \ldots, 34)$ denotes a generic student and j represents one of the three ideal student profiles. By following a methodology well known in the field of Econophysics (Mantegna, 1999), where it is common to compare the behavior of real stocks traded in financial markets with the characteristics of “ideal-type” stocks, like banking, industrial, service, etc., the “distances” between each student and the three ideal profiles (i.e. the student mental model profiles) were calculated by using the relationship:

$$d_{ij} = \sqrt{\frac{1 - r_{ij}}{2}}.$$

The general idea behind the use of this definition of distance between two elements i and j is that pairs of elements with positive correlation coefficient are “more similar” than pairs with correlation coefficient zero, or negative. In our case, when a student i never answers the questionnaire items by using strategies typical of a given profile j, $r_{ij} = -1$ and the related value d_{ij} assumes its maximum value, 1. When the student answering strategies are always be found in the same ideal profile j, $r_{ij} = 1$ and d_{ij} is 0.

We used the values d_{ij} to build a graph that can easily evidence if the three mental model categories really describe the real student behavior and if it is possible to identity clusters of student behavior with respect to the mental models.

Figure 1 shows the graph obtained by using our data, where each ideal student profile is represented as one of the vertex of a Reuleaux triangle, whose distance from any of the other two vertexes (i.e. ideal profiles) is equal to 1 (i.e. the maximum distance between two elements in our analysis). In this graph students are represented by S_i (where i again goes from 1 to 34) and are placed within the triangle according to their distances with respect to the three ideal student profiles.

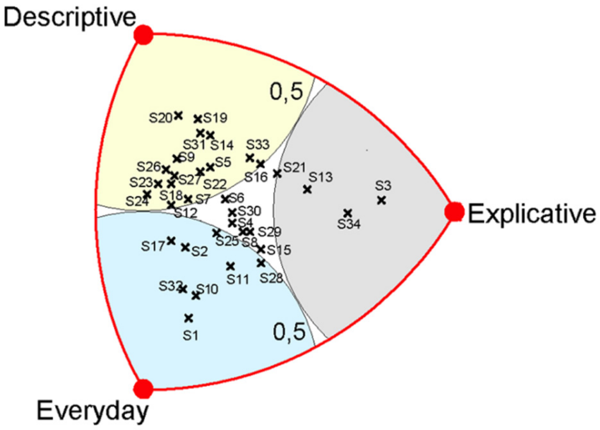


Figure 1: Graph of “distances” between real students and the three ideal student profiles

From Figure 1 it can be seen that many students are far away from a given profile of less than 0.5. This means that they appear to have answered the questionnaire items by putting into action well defined mental models. However, a number of students is distributed in proximity of the centre of the triangle; this means that their distances with respect to the three profiles are comparable, i.e. these students seem to use a variety of mental models when tackling the questionnaire items. Going into detail, 8 students can be classified as mainly putting into action Everyday-type strategies, 16 highlight the use of Descriptive-type ones (although many of them have distances near, or equal, to 0.5 with respect to this profile), and only four can be considered as mainly using Explicative-type mental models.

The analysis here reported is coherent with a more detailed study of the similarity between the students and the three ideal profiles (Fazio, Battaglia & Di Paola, 2013) performed by using a more complex approach based on Statistical Implicative Analysis (SIA) (Lerman, 1981; Lerman, Gras & Rostam, 1981a, 1981b).

INTERVIEW ANALYSIS

According to many research papers (Berg, 1989; Onwuegbuzie et al., 2012) a detailed analysis of the language used by each student during an interview, or when carrying out an activity involving human interaction, can provide evidence of the cognitive style(s) used when tackling a given issue or problem. Therefore, the interviews were audio recorded and then analyzed by the three researchers, partly on the basis of a search for 'indicator words/utterances' and specific aspects of students' answers which could help to answer the research questions. The analysis of the semantic properties of the student's language was based on the distinction made by the French psychologist Frederic Pauhlan between the sense and the meaning of a word and considering "the preponderance of the sense of a word over its meaning" (Vygotsky, 1986: p. 244): *""the sense is... the sum of all the psychological events aroused in our consciousness by the word. It is a dynamic, fluid, complex whole, which has several zones of unequal stability. Meaning is only one of the zones of sense, the most stable and precise zone. A word acquires its sense from the context in which it appears; in different contexts, it changes its sense."*

Several methods of analyzing interview excerpts are described in previous research on this subject. One such method involves the use of coding schemes to associate the number of indicator word/phrases that occur with specific forms of reasoning (Weber, 1990; Azmita & Montgomery, 1993). However, we acknowledge that *"the nature of language — in which any one grammatical form can be used to fulfill a range of pragmatic functions – renders any coding scheme of dubious value if used separately from a more contextually sensitive... type of analysis"* (Mercer et al., 2004: p. 372).

For this reason when analyzing the interview excerpts we tried to make sense of the students' use of indicator words/utterances in the specific context of the question itself (Onwuegbuzie et al., 2012; Leech & Onwuegbuzie, 2007), in order to highlight points of interest or controversial behavior in the related questionnaire answers. Furthermore, we also allowed the interviews, and the related qualitative analysis, to be driven by particularly relevant strategies used by students when answering the questionnaire items, and by their implications, as reported in the introductory remarks of each interview.

Table 2: Examples of key-words and phrases and specific aspects of the students' answers typical of the three categories of mental model

Everyday/Practical	**Descriptive**	**Explicative**
• (according to my) experience... • In real life... • Normally... • Real object... • ...	• I remember that... • I studied that... • I know that... • The formula says... • ...	• Molecular movement... • Is similar to... • microscopic... • interaction... • ...

Table 2 shows some examples of key-words and phrases and specific aspects of the students' answers that we used as evidence of the cognitive style(s) student used when tackling the interviewer answers.

Below we report some examples of answers given by our students to the interviewer questions. In them it is possible to recognize some key-words and phrases we identified as descriptors of a given mental model used to tackle the question.

Eleonora: *"... molecules act each other by means of electric forces..."*

Luca: *"... temperature is related to molecular movement , i.e. to molecular energy..."*

Fabiana: *"... as the mathematical formulas are similar, I think that temperature and energy/enthalpy should play the same roles."*

Matteo: *"... I now remember that when studying the vapour pressure equilibrium in liquids."*

Aldo: *"I know from my experience that... a minimum temperature must be reached in order to light a real life object, like... a match, if you strike it."*

Here, Eleonora and Luca highlight clear references to microscopic models (i.e. the use of explicative-type mental model) in answering the interviewer questions. Fabiana and Matteo highlight a Descriptive-like behaviour, with clear references to the use of mathematical formulas, and to the use of memory of studied subjects, to tackle the questions. Aldo shows to recall a real-life experience (striking a match) to tackle the question, highlighting an approach typical of Everyday-type mental model. The first four students can be found in figure 1 graph as actually being classified as Explicative (Eleonora, student S13, and Luca, student S34) or Descriptive (Fabiana, student S23, and Matteo, student S20). On the other hand, Aldo, student S31, is classified as a Descriptive mental model user in Figure 1, that, we recall it, is built only with data coming from the answers to the questionnaire items. This shows that a more in-depth analysis is needed in order to correctly classify a student in a given category, something that can be easily done with the joint use of qualitative interview analysis and quantitative methods. A more complete analysis of Aldo's answers to the interviewer questions, highlighting his use of mixed-type mental models when tackling with problems//situations, can be found in (Fazio, Battaglia & Di Paola, 2013), where many excerpts from student interviews, better characterizing the use we do in our study of interview analysis, can be found.

DISCUSSION AND CONCLUSIONS

The quantitative and qualitative data analysis reported above allow us to answer the research questions, which regard 1) the characteristics of the mental models students deploy when searching for explanations to phenomena/situations related to real-life and to subjects studied in previously attended courses, and 2) the consistency in students' deployment of mental models.

The similarity analysis allowed us to identify clusters of students whose answering strategies can be completely included into categories related to three different mental models. These categories highlight the reasoning procedures "ran" by students when searching for explanations about phenomena and/or proposed situations.

Many of the students, S_i, are plotted in Figure 1 graph with distances less than 0.5 with respect to one of the three profiles, highlighting a consistency in their use of a specific mental model when tackling with the situations proposed in the questionnaire items. On the other hand a significant number of students is distributed in proximity of the centre of Figure 1 Reuleaux triangle; this means that their distances with the three profiles are comparable. So, these students seem to use a variety of mental models when tackling the questionnaire items and highlight a lack of consistency in their deployment of mental models.

The analysis of the interviews allows us to go further and better characterize the student behaviour. Many of them clearly show to have more than one view about the nature and use of explications in science. Often strategies which are inefficient at correctly connecting mathematical modeling to real situations are revealed. Very often, reference to a well known mathematical model seems to stimulate a recalling procedure, i.e. a search in memory for examples that fit in with the formula, without a clear understanding of its physical meaning. Moreover, the analysis of interviews also highlight a significant use of approaches based on common-type knowledge, even in students who generally adopt descriptive strategies.

Our results are consistent with data from the literature (Bao & Redish, 2006; Maloney & Siegler, 1993; Carley & Palmquist, 1992; Corpuz & Rebello, 2011; Chittleborough & Treagust, 2007; Hrepic, Zollman & Rebello, 2005; Bao, 1999) showing that the mental models students deploy in creating explanations can be eclectic, and sometimes contradictory. In fact, many students of our sample use different kinds of reasoning, with particular reference to ones which are inefficient for correctly associating explanations to real situations. A significant presence of everyday or descriptive ideas in student answers is highlighted, in some cases even in students who generally use explicative strategies.

APPENDIX

Questionnaire items and the related answering strategies for each item on the basis of an a-priori/a posteriori analysis. The unforeseen strategies are in italics. In the answering strategies, numbers refer to the item, lowercase letters to the mental model category (practical/everyday (pe), descriptive (de) or explicative (ex)) and uppercase letters to the specific answering strategy.

1. **A puddle dries more slowly at 20 °C than at 40 °C. Assuming 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.

1peA The relevant quantities are not identified.
1peB The relevant quantities are not identified, but a description/explanation based on common sense is given.
1deA The relevant quantities are identified, but they are not used properly to give an explanation.
1deB Only temperature is identified as relevant, but the phenomenon is not correctly described.
1deC *Only temperature is identified as relevant. It is used to give a rough description of the phenomenon.*
1deD The phenomenon is described by means of the macroscopic variables pressure and volume, but a microscopic model is not identified.
1deE The phenomenon is described by means of the macroscopic variables temperature, energy and heat, but a microscopic model is not identified.
1deF The phenomenon is described by means of a mathematical formula, but a microscopic model is not identified.
1exA *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".*
1exB 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.
1exC The phenomenon is verbally described and a microscopic "functioning mechanism" is roughly sketched.
1exD The phenomenon is described by means of mathematical relations between macroscopic quantities and a microscopic "functioning mechanism" is found.

2. **In chemical kinetics it is well known that the rate of a reaction, u, between two reactants follows the Arrhenius law:**

$$u = A\mathrm{e}^{-\frac{E}{kT}}.$$

Describe each listed quantity, clarifying its physical meaning and the relations with the other quantities.

2peA The fundamental quantities are not described and/or only examples of its application to everyday-life phenomenology are given.
2peB Some quantities are mentioned, but no description of the process is given.
2deA The relevant quantities are found, but only a few are described in terms of their physical meaning.
2deB *The relevant quantities are found, but only described in terms of their mathematical meaning in the formula. No relation between them is identified.*
2deC The relevant quantities are found and correctly described in terms of their physical meaning. No relation between them is identified.
2exA The relevant quantities are found and correctly described in terms of their physical meaning. Some relations between them are identified.

2exB	The relevant quantities are found and correctly described in terms of their physical meaning. The relations between them are correctly identified.

3. **What do you think the role of a catalyst is, in the development of a chemical reaction?**

3peA	A definition of catalyst is given, which does not conform to the scientifically correct one.
3peB	A definition of catalyst based on an analogy with the concept of enzyme is given. The analogy is recalled without providing additional reasoning.
3deA	The catalyst is described as a substance which speeds up a chemical reaction. No additional explanation is supplied.
3deB	The catalyst is described as a substance which shifts the chemical equilibrium towards the products. No additional explanation is supplied.
3deC	The catalyst is described as a substance which speeds up a chemical reaction. An explanation is given using common language.
3deD	The catalyst is presented as a substance which shifts the chemical equilibrium towards the products. An explanation is given using common language.
3deE	The catalyst is presented as a substance which speeds up a chemical reaction. The concept is generically described in terms of energy.
3deF	The catalyst is presented as a substance which shifts the chemical equilibrium towards the products. The concept is generically described in terms of energy.
3deG	*The catalyst is presented as a substance which speeds up a chemical reaction. The concept is described by simply citing the energy gap concept, without any explanation.*
3deH	*The catalyst is presented as a substance which shifts the chemical equilibrium towards the products. The concept is described by simply citing the energy gap concept, without any explanation.*
3deI	*The role of a catalyst in a chemical reaction is discussed referring to the energy gap concept, but only in macroscopic terms.*
3exA	The role of a catalyst in a chemical reaction is discussed taking into account the energy gap concept. The concept is explained considering a microscopic model regarding collisions between molecules.
3exB	The role of a catalyst in a chemical reaction is discussed taking into account the energy gap concept. The concept is explained considering a microscopic model which links the energy gap concept with the molecular energy.

4. **Can you give your own microscopic interpretation (model) of the Arrhenius law?**

4peA	Everyday-life concepts are mentioned, without any correct relation to the Arrhenius law.
4deA	Scientific concepts, such as energy, temperature or molecular thermal agitation, are mentioned, but they are not correctly related to the Arrhenius law.
4deB	Arrhenius law is described as a mathematical function of T or E. No explanation of the meaning of these quantities is given.

4deC Arrhenius law is described as a mathematical function of both T and E. No explanation of the meaning of these quantities is given.

4deD 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.

4deE 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.

4deF *Arrhenius law is described outlining the physical quantities involved. Collision theory is sometimes mentioned, but a clear reference to a microscopic model is not always present.*

4exA A generic explanation based on a microscopic model of collisions between molecules is given. The activation energy concept is outlined but its relation with kT is not clearly presented.

4exB 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 which can be explained by a similar model?**

5peA A few phenomena not related to the model are mentioned. No explanation is given.

5peB A few phenomena not related to the model are mentioned. An explanation is given using common language.

5deA A few phenomena not related to the model are mentioned. An explanation is given using mathematical formulas.

5deB Some phenomena related to the model are mentioned, but these are limited to the context of the attended graduation program (chemical engineering). An explanation is given using mathematical formulas.

5deC *Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account, but a clear explanation is not given.*

5deD Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account. An explanation is given using mathematical formulas.

5exA Some phenomena related to the model are mentioned, but these are limited to the context of the attended graduation program (chemical engineering). An explanation is given outlining a common microscopic model.

5exB *Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account. An explanation is given outlining a common microscopic model, but energy and temperature are not clearly interrelated.*

5exC Some phenomena related to the model are mentioned, and non-chemical phenomena are also taken into account. An explanation is given outlining a common microscopic model. The role of energy and temperature in the model is clearly discussed.

6. **Which similarities can be identified in the previous phenomena? Is it possible to find a common physical quantity which characterizes all the systems you discussed in the previous questions?**

6peA	No similarities are detected and questions 1) and 2) are identified as being related to a different context on the basis of everyday-life reasoning.
6deA	*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 which are not really relevant to the correct explanation of the questions.*
6deB	*A few correct similarities are found, but physical quantities are given, which are not really relevant to the correct explanation of the questions.*
6deC	Incorrect similarities are found on the basis of a mathematical formula.
6deD	A few correct similarities are found on the basis of a mathematical formula.
6deE	Correct similarities are found, but E and T are not always considered common to all phenomena.
6deF	Some correct similarities are found. E or T is considered to be characteristic of the various phenomena, but a clear justification is not given.
6deG	Some correct similarities are found. E or T is considered to be characteristic of the various phenomena, clearly explaining why.
6deH	Some correct similarities are found. E or T is considered to be characteristic of the various phenomena, but the relevance of their ratio in explaining the energy threshold processes is not clearly presented.
6exA	Some correct similarities are found. E or T is considered to be characteristic of the various phenomena. The activation energy role is correctly discussed in all the mentioned phenomena, but only in macroscopic terms.
6exB	Some correct similarities are found. E or T is considered to be characteristic of the various phenomena. The activation energy role is correctly discussed in all the mentioned phenomena, on the basis of a microscopic model.

REFERENCES

Azmita, M. & Montgomery, R. (1993). Friendship, transactive dialogues, and the development of scientific reasoning. *Soc. Dev.*, 2(3), 202–221.

Bao, L. (1999). *Dynamics of student modeling: A theory, algorithms, and application to quantum mechanics* [Dissertation thesis]. College Park: University of Maryland.

Bao, L. & Redish, E. F. (2006). Model analysis: Representing and assessing the dynamics of student learning. *Phys. Rev. ST Phys. Educ. Res.*, 2, 010103.

Berg, B. (1989). An introduction to content analysis. In B. Berg (Ed.), *Qualitative Research Methods*, Boston: Allyn & Baron Press.

Brewer, J. & Hunter, A. (2006). *Foundations of multimethod research: synthesizing styles.* Thousand Oaks: Sage Publications.

Brousseau, G. (1997). *Theory of didactical situations in mathematics.* Dordrecht: Kluwer Academic.

Carley, K. & Palmquist, M. (1992). Extracting, representing and analyzing mental models. *Social Forces*, 70(3), 601–636.

Chittleborough, G. & Treagust, D. F. (2007). The modelling ability of non-major chemistry students and their understanding of the sub-microscopic level. *Chemistry Education Research and Practice*, 8(3), 274–292.

Corpuz, E. D. & Rebello, N. S. (2011). Investigating students' mental models and knowledge construction of microscopic friction. I. Implications for curriculum design and development. *Phys. Rev. ST – Phys. Ed. Res.*, 7, 020102.

Fazio, C., Battaglia, O. R. & Di Paola, B. (2013). Investigating the quality of mental models deployed by undergraduate engineering students in creating explanations: The case of thermally activated phenomena. *Physical Review Special Topics —- Physics Education Research*, 9, 020101.

Gilbert, J. K. & Boulter, C. (1998). Learning science through models and modelling. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education.* Dordrecht: Kluwer Academic Publisher.

Gilbert, J. K., Boulter, C. & Rutherford, M. (1998). Models in explanations: Part 1, horses for courses? *Int. J. Sci. Educ.*, 20(1), 83–97.

Gower, J. C. (1966). Some distance properties of latent root and vector methods used in multivariate analysis. *Biometrika*, 53(3–4), 325–338.

Hrepic, Z., Zollman, D. A. & Rebello, N. S. (2005). Eliciting and representing hybrid mental models. In *Proceedings of the NARST 2005.*

Johnson-Laird, P. N. (1983). *Mental Models.* Cambridge: Cambridge University Press.

Leech, N. L. & Onwuegbuzie, A. J. (2007). An array of qualitative analysis tools: A call for data analysis triangulation. *School Psychol. Quart.*, 22(4), 557–584.

Lerman, I. C. (1981). *Classification et Analyse Ordinale Des Données.* Paris: Dunod.

Lerman, I. C., Gras, R. & Rostam, H. (1981). Elaboration et évaluation d'un indice d'implication pour des données binaries. I. *Math. Sci. Hum.*, 74, 5–35.

Lerman, I. C., Gras, R. & Rostam, H. (1981). Elaboration et évaluation d'un indice d'implication pour des données binaries. 2. *Math. Sci. Hum.*, 75, 5–47.

Maloney, D. & Siegler, R. S. (1993). Conceptual competition in physics learning. *Int. J. Sci. Educ.*, 15(3), 283–295.

Mantegna, R. N. (1999). Hierarchical structure in financial markets. *Eur. Phys. J.*, 11(1), 193–196.

Marton, F. (1988). Describing and improving learning. In R. R. Schmeck (Ed.), *Learning strategies and learning styles.* New York: Plenum Press.

Marton, F. & Booth, S. (1997). *Learning and awareness.* Mahwah: Lawrence Erlbaum Associates.

Mercer, N., Dawes, L., Wegerif, R. & Sams, C. (2004). Reasoning as a scientists: ways of helping children to use language to learn science. *Brit. Educ. Res. J.*, 30(3), 359–377.

Onwuegbuzie, A. J., Leech, N. L., Slate, J. R., Stark, M., Sharma, B., Frels, R., Harris, K. & Combs, J. P. (2012). An exemplar for teaching and learning qualitative research. *Qual. Rep.*, 17(1), 16–77.

Sperandeo-Mineo, R. M., Fazio, C. & Tarantino, G. (2006). Pedagogical content knowledge development and pre-service physics teacher education: a case study. *Res. Sci. Ed.*, 36(3), 235–268.

Tashakkori, A. & Teddlie, C. (Eds.). (2003). *Handbook of mixed methods in social & behavioral research.* Thousand Oaks: Sage Publications.

Vygotsky, L. S. (1986). *Thought and Language.* Cambridge: MIT Press.

Weber, R. P. (1990). *Basic content analysis.* Beverly Hills: Sage Publications.

CLAUDIO FAZIO
ONOFRIO ROSARIO BATTAGLIA
ROSA MARIA SPERANDEO-MINEO
UOP_PERG (University of Palermo — Physics Education Research Group), Department of Physics and Chemistry, University of Palermo, Italy

Scientia in educatione 8(Special Issue), 2017
p. 165–171
ISSN 1804-7106

Student's Video Production as Formative Assessment

Eduardo Gama, Marta F. Barroso

Abstract

Learning assessments are subject of discussion both in their theoretical and practical approaches. The process of measuring learning in physics by high school students, either qualitatively or quantitatively, is one in which it should be possible to identify not only the concepts and contents students failed to achieve but also the reasons for the failure. We propose that students' video production offers a very effective formative assessment tool to teachers: as a formative assessment, it produces information that allows the understanding of where and when the learning process succeeded or failed, of identifying, as a subject or as a group, the deficiencies or misunderstandings related to the theme under analysis and their interpretation by students, and it provides also a different kind of assessment, related to some other life skills, such as ability to carry on a project till its conclusion and to work cooperatively. In this paper, we describe the use of videos produced by high school students as an assessment resource. The students were asked to prepare a short video, which was then presented to the whole group and discussed. The videos reveal aspects of students' difficulties that usually do not appear in formal assessments such as tests and questionnaires. After the use of the videos as a component of classroom assessments and the use of the discussions to rethink learning activities in the group, the videos were analysed and classified in various categories. This analysis showed a strong correlation between the technical quality of the video and the content quality of the students' argumentation. Also, it was shown that the students do not prepare their video based on quick and easy production; they usually choose forms of video production that require careful planning and implementation, and this reflects directly on the overall quality of the video and of the learning process.

Key words: assessment and evaluation, video production, learning physics, physics education.

INTRODUCTION

Teaching and learning — to find out if the connection was made it is necessary to assess learning. In most cases, teachers do not think extensively about how they assess learning; they basically do what they have previously experienced.

But assessment can be a fundamental tool in the learning process. If taken as a formative assessment tool (Black, 1998), it is possible to retrace steps in teaching, to rethink classroom activities and developments, therefore improving the learning capabilities of the students.

In general, the teaching process does not aim uniquely at content subject learning. It involves skills related to the interaction with peers, with autonomy and intellectual independence, and somehow with the completion of projects and actions, as happens in real life. But assessments in general do not take these complementary and important aspects into account. It is very difficult to develop an assessment action with pencil and paper within a limited period of time.

This paper presents an activity used as a formative assessment tool in high school physics education. The students were asked, after formal instruction, to produce a short video on one of the themes studied during term. They have to work in groups, and also write the conception and production mechanisms of the video.

After the videos were produced, the teacher watches all of them and prepares a video presentation and discussion session. The discussion includes all the students, and the process grades the student with a small part of the final grade.

The posterior analysis of the videos reveal what was an unexpected product of the activity: they produce a fine assessment tool, for they reveal some aspects which cannot be easily assessed in content learning. The videos were analysed in a series of aspects, and the results allow us to conclude that video production by high school students can be used with good results to assess learning.

PRELIMINARY CONSIDERATIONS

The new information and communication technology has profound impact on young students. They deal with music, videos, and communication in new ways that are mostly not present at school activities.

The accessibility of mobile phones, tablets, and video cameras to almost every house, even in not rich regions over the world, poses some new possibilities to physics teaching. One of them is the use video production in classrooms. According to Vonk (2012):

"Like it or not, we seem to be using video in almost exactly the same way that we have used writing. And like it or not, a video analog has saddled up next to virtually every form of writing known, except in academia, where most professors I know are still requiring only written work."

The use of videos in classroom has been subject of many discussions. One of the most interesting ones is related to the use as an approach to laboratory experiments (Pereira et al., 2012).

But there is another possibility, related to learning assessments. The definition of learning is related to the complex construct of understanding. To have a measurement of understanding, an operational definition of it is necessary — and any operational definition needs to be broad enough so that the concept of learning and understanding is not restricted to answering a few simple questions on concepts, or solving some standard exercises, or completing some preordered activity. According to White and Gunstone (1992: p. 7):

> *"We contend that assessment in schools is too often narrow in range. The oral questions that teachers ask in class and their informal and formal written tests usually are confined to requiring short answers of a word or two or a number, a choice from a few alternatives, or 'essays' of various lengths. While there is nothing wrong with these tests, they are limited in type. Limited tests provide a limited measure of understanding, and, worse, promote limited understanding. We advocate use of diverse probes of understanding as an effective means of promoting high quality learning."*

In particular, when it comes to formative assessment, that is, the assessment during the course, which is intended to diagnose the comprehension of the themes, the progress students are making, and using that information being able to reorganize students' learning and teaching activities, video production is a very interesting tool.

In making a video, students have to access their cognitive resourses and to define the strategies that allow them to fulfill what was asked by the teacher. This activity has some meta-cognitive characteristics, for it makes the students think about their actions, planning and replanning them, trying different language forms till they find the appropriate one, recognizing and overcoming their limitations in the process of production. It is an assessment tool for the teacher, and much more than that: it is a learning resource, complementing the ones used by teachers. Also, the aspect of socialization between the students, provided by the audiovisual format, can provide new questions, new difficulties and reveal aspects of concepts and contents that were not clear.

Another characteristic of video production by students is that it can be though as a means of acquiring meaningful learning in the sense of Ausubel's theory (Ausubel, Novak & Hanesian, 1978). According to it, any new information has to interact with a previous information already present in the cognitive structure of the student. The teacher needs to know what his students know, so that he can provide activities that allow the assimilation and reorganization of their cognitive structure. In producing a video on a physics theme, the students have to access their cognitive resources frequently; the production implies a ressignification of concepts and reorganization of the cognitive structure, specially when students have to work collaboratively. Also, it is easier for the teacher to evaluate if learning was mechanical. This evaluation occurs in three occasions: during video production, when students ask the teacher for help, during the analysis of the video by the teacher, and in the classroom discussion of all the videos, when the students have to interact with other groups.

Description of the assessment process with the students

The use of video production by students as an assessment tool took place in a high school in Rio de Janeiro. This school, Colégio Pedro II, named after the second and last emperor of the country, is one of the federal and traditional institutions of basic education in Brazil. The mechanism by which students are accepted in this school is chance, and this means that classes have a multicultural and multieconomic profile.

The themes in physics presented to students in high school first year (14–15 years) were geometrical optics and heat, in second year (15–16 years) introductory mechanics, and third year (16–17 years) electricity, oscillations and waves, and sound.

The teacher has some concepts to explore every term, discussed in the physics team of teachers. The presentation of the themes is mainly done in traditional ways: classroom activities based on lecturing, exercises, videos and discussions.

After the term (three months), the students were asked to produce a video that should be used as part of their grades on the term. They should gather into groups of no more than 5, choosen by themselves, and prepare a video on one of the subjects studied. There were no constraints other than the duration (between 1 and 10 minutes) and the character of being a presentation to colleagues. The format, the subject and the means were all their choice. And they should also write a short paper, of no more than 2 pages, describing what was produced, how it was produced, with a brief explanation of the physics involved.

The teacher collects and watches all the videos, and reads all the written texts. He or she presents comments and corrections to the written texts, and prepare comments and discussions on the videos. The analyses involve objective aspects like the technical format, the physics involved, and the connection between the proposal and the final video. Special care was taken on the physical content of the theme.

Finally, there was a video session for the classroom. In this opportunity, the teacher uses every chance to improve the learning of the concepts and the interaction of the students with themselves and with physics.

THE ANALYSIS OF THE VIDEOS

The videos were gathered and analysed. The aspects choosen for the analysis were related to the research question: is video production by students a reliable assessment tool?

With this in mind, the videos were analysed on three main categories: the physics content presented, the format choosen to present this content, and general aspects.

The content of the video regarded basically if the physics involved was correct, if the presentation was clear, if it was compatible with the proposal. The technical format was divided into the type used (a movie, a superposition of slides, an experiment, a cartoon, and some mixed types). The general aspects are related to questions like if the video showed internal logic and/or internal coherence and consistency, if there is an activity like an experiment to present some physics phenomena, if there was an explanation of the results of the experiment and about the quality of the argumentation.

In this paper, it is presented the results obtained with classes during the year of 2011. The use of videos was mantained in the years after. In Table 1, we present the global data of 2011: 55 videos were produced, and 232 students participate (131 female, 101 male), divided by year in school.

Table 1: The students involved and videos produced in each group

	videos	students
1st year high school	12	55
2nd year high school	22	98
3rd year high school	19	75
missing	2	4
Total	55	232

Table 2: The themes of the videos on introductory physics

dynamics	37 (67%)
geometrical optics	7
thermal physics	2
mechanical waves	3
electricity	1
waves and optics	2
contemporary issues	1
generalities	2

In Table 2, we show the division of the videos on physics themes. One can notice that elementary dynamics is the content that most videos treat; and this can be seen by the majority of students in 2nd year students, and their main theme is introductory mechanics.

In connection to the assessment of the physical content, it was observed that 35 % of the productions were correct and 45 % were partially correct. Also, the physical ideas were presented clearly in almost half of the videos (47 %), the connection between proposal and product was satisfactory in 75 % of the videos, and there was a logical sequence in the videos in 87 %; these data are shown in Tables 3 and 4.

Table 3: The videos analysed in connection to the physical content

The physical content is correct			The presentation is clear		
correct	19	35 %	yes	26	47%
partially correct	25	45 %	no	7	13 %
incorrect	8	15 %	partially	21	38 %
not applicable	3	5 %	not applicable	1	2 %

Table 4: The general aspects of the analysed videos

There is a connection between proposal and product			There is a logical sequence		
yes	41	75 %	yes	48	87 %
no	3	5 %	no	0	0 %
partial	8	15 %	partial	5	9 %
not applicable	2	4 %	not applicable	2	4 %

The videos were presented in a series of formats; about 33 % of them were movies, 27 % were a combination of videos and slide presentations, and the rest was presented as a theatrical action scene, comics, only slide presentation in sequence, etc. Almost all of them (84 %) used music, but of this use of music was just incidental, background (93 %), and not part of the story.

It can also be noticed that although in only 22 % of the videos the students prepared an experimental situation, there was some experiment shown in 64 % of them, as presented in Table 5.

The surprising aspect was the correlation observed between the technical quality of the video and the exactness of the physics discussed: only 7 % were technically poor. 42 % of the videos were technically very well done; and from these, 90 % were entirely conceptually correct.

Table 5: The use of experiments in the images

There was preparation of experiment			An experiment was filmed		
yes	12	22 %	yes	35	64 %
no	43	78 %	no	20	36 %

WHAT THE VIDEOS REVEAL ABOUT LEARNING PHYSICS

The videos provided a very useful assessment tool. The students were given the possibility of talking physics, and in it they revealed what it takes a long and hard way for the teachers to find out. In general, this kind of evaluation is only possible with long individual interviews, or carefully prepared (with the right questions) questionnaires.

As an example of a video with reveals difficulty in learning, a video can be mentioned, one called by the authors "Sports and Physics". The image of the video is a 100 m man race, with U. Bolt winning. A small part of the words read can be cited:

"In an atletic race, the athlet shall keep his body upright while he completes the curve. (...) In this case, the centripetal force he produces while on the curve using the incline acts against the centrifugal force that sends him outwards."

In this example, the whole text presents many incorrect conceptions, and it can be noticed the confusion about concepts related with elementary dynamics (on inertial forces, centripetal acceleration, and third law). Also, this video is presented as a reproduction of TV news, technically careless in the production.

Another example shows what can be obtained: in a video named "Law of Gravity", a female student receives his exam graded zero, and a friend teaches her about gravity by rolling down the stairs. She says:

"What is gravity? According to Newton's law, not this Newton, Isaac Newton, gravity is the force of attraction that material bodies exert on one another. (...) Loosely speaking, it is the law of physics that hold things attached to Earth. It is what makes this happen."

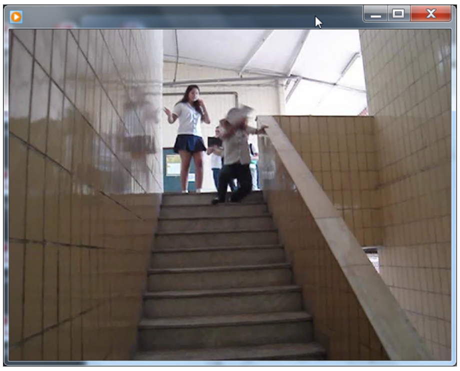


Figure 1: Law of Gravity

In this situation, it can be seen that the students are amusing themselves, and using a language that clearly corresponds to their age. They make a joke with one of the authors, named Newton, and with rolling down the stairs, as shown in Figure 1.

These examples, among many others, reveal aspects of physics learning and of how students considered the task of producing a video that can provide an interesting discussion in the classroom.

CONCLUSIONS

This paper proposes that the production of short physic videos is a very appropriate formative assessment tool.

The use of mobile phones, tablets and cameras are disseminated nowadays, and students do use them often. In school, the teachers are still reluctant to understand the possibilities of use of these tools as part of their teaching materials, as suggest by Vonk (2012).

In fact, videos can be used for data collection in physics and in physics teaching. And can also provide a very useful assessment tool, another kind of probe as proposed by White and Gunstone (1992).

The proposed activity is an extra class activity, producing a video and reporting its production. This activity requires more skills than just learning physics: requires cooperative team work, active participation of the students in their process of learning (Ausubel, Novak & Hanesian, 1978), and are related to the use of technology they are familiar with.

The videos allowed the teacher to check precisely how the students interpreted what he or she teaches, still in time to promote changes. The videos revealed how the students think about the topics, and surprisingly they seem to have spent time in preparing the videos. It was noticed that there is a strong correlation between the high technical quality and the quality of content.

The main conclusion is that the use of video production by students in physics high school classes is a possible and reliable formative assessment tool.

Acknowledgement

This work was done under Brazilian Grant from CAPES/Observatório da Educação.

References

Ausubel, D. P., Novak, J. D. & Hanesian, H. (1978). *Educational psychology: A cognitive view.* New York: Holt, Rinehart and Winston.

Black, P. (1998). *Testing: Friend or foe? The theory and practice of assessment and testing.* London: Routledge and Falmers.

Pereira, M. V., Barros, S. S., Rezende Filho, L. A. C. & Fauth, L. H. A. (2012). Audiovisual physics reports: students' video production as a strategy for the didactic laboratory. *Physics Education*, 47, 44–51.

Vonk, M. (2012). Video is the new writing: Are you literate? *Physics Today.* Available at http://www.physicstoday.org/daily_edition/points_of_view/video_is_the_new_writing_are_you_literate

White, R. & Gunstone, R. (1992). *Probing understanding.* London: Routledge and Falmers.

Eduardo Gama
Colégio Pedro II, Rio de Janeiro, Brazil

Marta F. Barroso
Universidade Federal do Rio de Janeiro, Physics Institute, Rio de Janeiro, Brazil

Scientia in educatione 8(Special Issue), 2017
p. 172–181
ISSN 1804-7106

Development of Interest in Particle Physics as an Effect of School Events in an Authentic Setting

Kerstin Gedigk, Michael Kobel, Gesche Pospiech

Abstract

The Particle Physics Masterclasses are events offered by the "Netzwerk Teilchenwelt", a German network of particle physicists, students and teachers with the intention to make original data from CERN available for own measurements of students. These events were evaluated in 2011/2012. The investigation deals with their effect on the interest development of the youth participants, especially in particle physics. With a focus on the role of different event properties, it can be shown that besides the perceived challenge and comprehension, also authenticity is an important factor for the students' interest development.

Key words: interest, evaluation study, Masterclasses, particle physics.

INTRODUCTION

The aim of physics education consists not only of teaching the physical contents, but also to a large extent of giving an insight into the process of physics research, into recent research topics and into the fundamental nature of physics and thereby developing the interest of students in physics. These objectives strongly correspond to the aims of the 'Particle Physics Masterclasses'. But it is also well known that "investigations in different countries showed, that the interest in mathematics and in science subjects (. . .) in the secondary schools decreases" severely (Krapp, 2006: p. 288). How masterclass events and especially the authentic setting of these events have an effect on this interest development of high school students is one of the main questions which should be answered by an evaluation study.

THE "NETZWERK TEILCHENWELT"

The so called "Particle Physics Masterclasses" are offered by the German "Netzwerk Teilchenwelt" (English: Network Particle World) including 24 German particle physics research institutes and CERN[1]. It is a network between scientists, high school students and teachers. It was founded in 2010 inspired by the "International Hands On Particle Physics Masterclasses", with the idea, to open these appreciated annual events (see e.g. Johansson et al., 2007: p. 640) to more students, all over Germany and throughout the year. Another main concept to bring this network to life was to create a community in which interested students, teachers and particle physicists can be in an active exchange about particle physics, beyond just coming in contact with each other at a one-time event.

The network offers students and teachers the participation in 4 ascending levels. For the school students these different levels are shown in Figure 1. The Particle Physics Masterclasses themselves form the basic level of the program. If the students are interested in obtaining a deeper insight into particle physics beyond participation in a Masterclass they can join the higher levels. The possible activities range from transferring their knowledge about particle physics to conducting own research projects linked to (astro-) particle physics. For teachers a similar 4-level program is made available by the network. Further information about this network can be found at Gedigk, Glück & Kobel (2011).

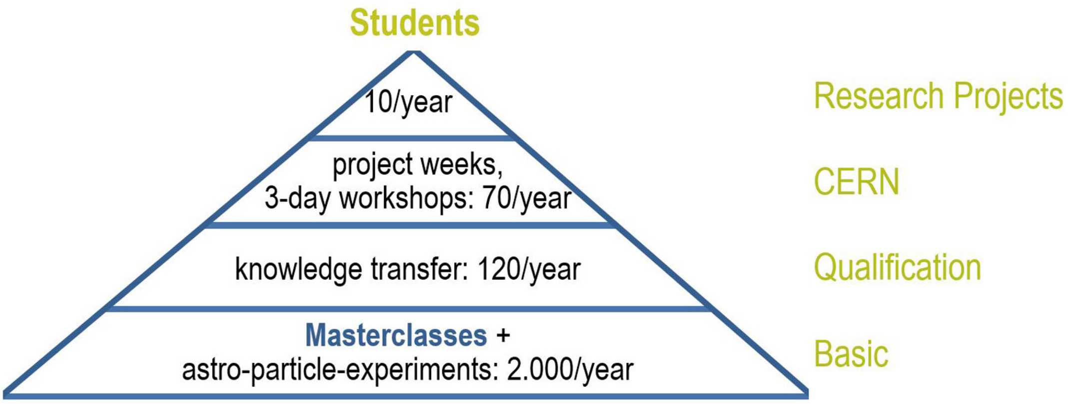


Figure 1: The 4-level programm of "Netzwerk Teilchenwelt". At each level the typical number of participating students is given

---

[1] European Organization for Nuclear Research (near Geneva/Switzerland).

THE PARTICLE PHYSICS MASTERCLASSES

The Particle Physics Masterclasses mostly take place in schools and last between 4 to 6 hours. The facilitators of these events are in most cases young particle physicists, e.g. PhD or Master students. During a Masterclass the scientists give an introduction into particle physics research, e.g. in the "Standard Model of Particle Physics", how the research community works together, which questions should be answered by the actual research, etc. Afterwards the young participants get an introduction how to visually identify particles from their traces in the detector. After an introductory exercise the participants make own measurements with original data from CERN. The students work in pairs to classify 50 to 100 events into various categories. Then the results of the groups are combined and discussed. With statistical methods they arrive at fundamental results which can be compared with predictions of the "Standard Model of Particle Physics".

There are two different kinds of data offered for the Particle Physics Masterclasses: one from CERN‘s Large Electron Positron Collider (LEP), which was used from 1989 to 2000 and another from the Large Hadron Collider (LHC), which has been in operation since 2010 at CERN. More information about these measurements can be found at (Bilow et al., 2011).

THE AIMS OF THE MASTERCLASSES AND THEIR AUTHENTIC SETTING

The overarching aim of the Masterclasses is to give an insight into the actual particle physics research in an authentic setting. Another goal is to stimulate the interest of individual students to voluntarily join the higher levels of the network program. Although the Masterclasses take place in schools there are different factors which create an authentic learning environment for the participants. Besides the contact with real scientists there is also the measurement with original data from CERN and the work with graphical visualisation software, which is very close to the one used at CERN. Moreover, guided by the scientists, the students use similar methods to interpret and compare their results with the predictions within the Standard Model.

RESEARCH QUESTIONS

In the evaluation study it is investigated, if the authentic setting of this one-day event is suitable to influence the interest of students: Are students' interests in physics as well as in particle physics fostered by a Masterclass participation? Can long-term effects be seen? Are there any differences noticed in the interest development between different participant groups (e.g. gender, age, type of school, etc.)? Which event properties are related to interest changes? Can factors be identified, which are crucial for a positive perception of the events? Moreover the evaluation study, which is presented below, makes it possible to say something about the increase in the participants' knowledge and to compare the Masterclasses' effects with results of other recent studies.

THE EVALUATION STUDY

The evaluation study mainly deals with the students' interest. The person-object-theory by Krapp creates the basis for the current investigation: "Interest designates a relationship of particular importance between a person and an object (. . .)" (Krapp, 1992: p. 307). The more often and the more intensive a person deals with the object the more stable this relationship becomes. Furthermore, the development of this relationship also depends on the situation or the context in which the person is operating with the object (Krapp, 1992: p. 308). In educational research there is an established distinction between the students' interest in the school subject "physics" and in the special physical topics (e.g. Hoffman, Häußler & Lehrke, 1998: p. 19). For the special interests there are three different dimensions identified: the learning content, the context in which the content appears and the activities which can be connected to the topic (Hoffman, Häußler & Lehrke, 1998: p. 26).

To measure changes in the students' interests the evaluation study is structured in a pre- post- follow-up design, which means that the participants were evaluated at the beginning, at the end of the Masterclass and again after a 6 to 8 week period. With the follow-up evaluation the sustainability of the Masterclasses can be investigated.

DESCRIPTION OF THE QUESTIONNAIRES

Based on this theoretical basis and recent results on informal out-of-school learning environments (e.g. Engeln, 2004; Pawek, 2009), the questionnaires were developed. Figure 2 shows a selection of variables.

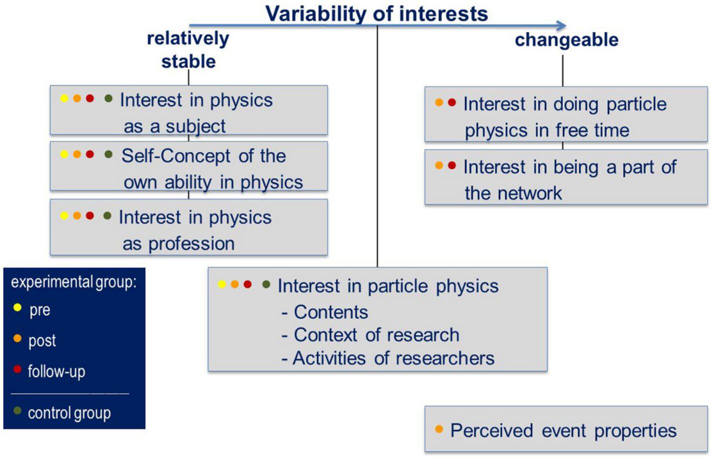


Figure 2: Selection of evaluated variables with the assumed stability

Because particle physics only plays a small role in the German school curricula, the special interest in this topic is assumed to be influenceable. For joining the higher levels in the network program beyond attending a Masterclass, the interest in doing particle physics in free time and in being a part of the network are the crucial variables.

Although the Self-Concept in physics does not directly belong to the interest variables, it is assumed to be relatively stable. Like the interest in physics as a subject and the interest in physics as profession it was created over several years of physics education.

For the questionnaires, which were piloted before, items with a 5-point Likert scale were used. Examples of the items and the computed internal-consistency coefficients (Cronbach's alpha) of the variables can be seen in the tables 3 and 4 in the annex.

SELECTED RESULTS OF THE STUDY

The evaluation study was conducted from October 2011 until May 2012 in 25 Masterclasses with about 500 students ("experimental group"). Additionally a "control group" has been evaluated, i.e. high school students who did not take part in a Masterclass.

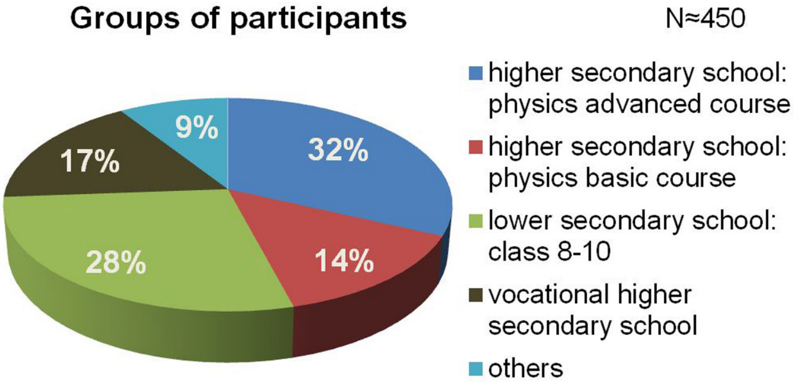


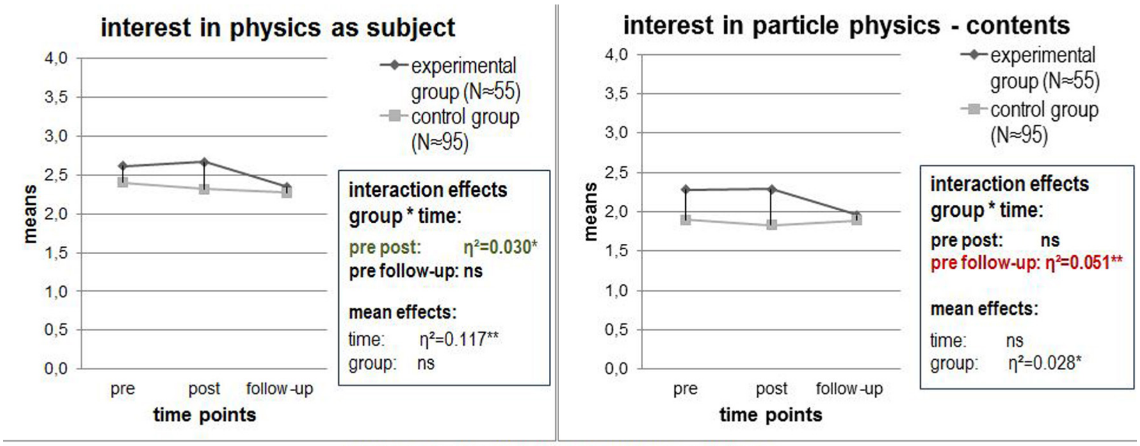
Figure 3: Participants of the experimental group

The "experimental group" consists of four main groups: students of the higher secondary schools (class 11 to 13) divided into the physics advanced and the physics basic course, students who visit the lower secondary school mainly in class 10 and older students who attend a vocational higher secondary school (see Figure 3). About 40 students of the experimental group attend another school form. Excluded were about 40 participants of the study, which already had attended a Masterclass before the evaluation. A fifth of the experimental group is female. The evaluation was conducted in 8 LEP- and 17 LHC-Masterclasses.

COMPARISONS BETWEEN THE EXPERIMENTAL AND THE CONTROL GROUP

For the comparison between the "experimental group" and the "control group" an analysis of variance with repeated measurements is used. Figure 4 shows selected results for participants attending class 10 of lower secondary schools- results of the higher classes are still under study. In these comparisons just students are included, who participated in a Masterclasses with their whole class, implying that the students in experimental group as well as in control group are not selected. Concerning these analyses of variance only the interaction effects between group and time are interesting, because these say something about the effect of the Masterclasses (Rudolf & Müller, 2012: p. 121). The separate effects of time and group on the mean are given only for information in the following figures.

For quantifying an effect size we calculate in a variance analysis the fraction η^2 of the total variance that is attributed to the effect (Rudolf & Müller, 2012: p. 115). For the interest in physics as subject the calculated effect size η^2 shows a small positive short-term effect but no long-term effect (Bortz & Döring, 2006: p. 606). No effects whatsoever were seen for the class 10 students for the Self-Concept and the interest in physics as profession. The analysis of the amount of the students' interest in particle physics, e.g. in the contents (see Figure 4), show no short-term effects but small negative long-term effects. These developments correspond to the



* significant with $p<0.05$; ** significant with $p<0.01$; **ns**: not significant

Figure 4: Analysis of variance with repeated measurements for the interest in physics as subject (left) and for the interest in the particle physics' contents (right) for classes 10

results of similar recent studies (Engeln, 2004; Pawek, 2009). It is noteworthy that the experimental group shows significant higher interest values in the pre- and post-test, whereas in the follow-up test the values of both groups are similar. It seems that the prospect of participating in a Masterclass causes an increase in the students' physics interests even before they started.

The influence of the perceived event features

How the Masterclass' participants perceive the events was also part of the evaluation of the "experimental group". An overview is represented in Figure 5. All features are very positively perceived: they are rated higher than 2 by most participants. The best rated feature is "support and atmosphere", which shows that the young facilitators are able to create an agreeable learning environment. The second best rated feature is "authenticity" which indicates that the authentic setting is noticed as such by the students.

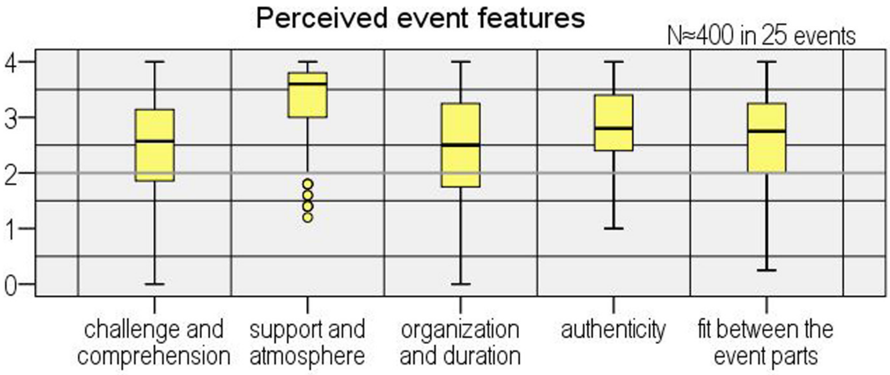


Figure 5: Masterclass' features as perceived by the "experimental group". The yellow boxes cover 50 % of the students, the black lines cover 100 %, dots are outliers

Table 1 shows the influence of these perceived event features on the interests beyond the Masterclasses and the short- and long-term development of the particle physics' interest dimensions (also see Figure 6). "Support and atmosphere" and the "fit between the event parts" are excluded from the regression analysis, because of

Table 1: Influence of perceived event features on students' interests — Multiple regression: standardized regression coefficients

		Challenge and comprehension	Authenticity	Organization and duration
Change of interest in particle physics (pre–post) $N \approx 365$	Contents	0.13**	**0.23****	ns
	Context of research	0.22**	**0.25****	ns
	Activities of researchers	ns	**0.19****	ns
Change of interest in particle physics (pre–follow-up) $N \approx 280$	Contents	**0.16***	ns	ns
	Context of research	**0.34****	ns	ns
	Activities of researchers	**0.15***	ns	ns
Interest in doing particle physics in free time (post) $N = 381$		**0.32****	**0.36****	0.11*
Interest in being a part of the network (post) $N = 375$		**0.32****	**0.35****	ns

*significant with $p < 0.05$; **significant with $p < 0.01$; ns: not significant

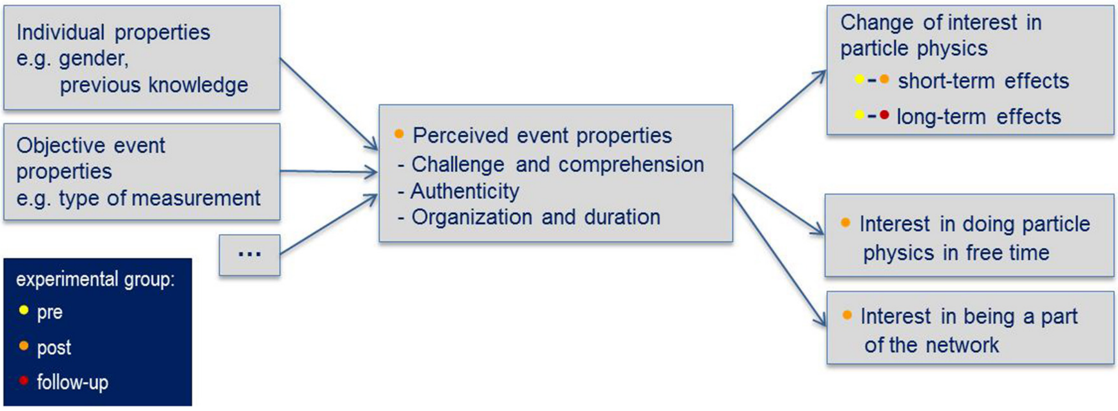


Figure 6: Influencing factors on perceived event features and their influence on interests

occurring multicollinearity effects (Rudolf & Müller, 2012: p. 51–54). For determining the change of interests the difference of the interest values between the respective time points was used. The standardized regression coefficients show that "authenticity" has the most important influence on the short-term change of the interest in particle physics, "challenge and comprehension" on the long-term change and both of them are important for the interests beyond the Masterclass participation.

For deeper analysis we looked for possible influences on the perceived event features. On the one hand there are the individual properties of the students, which have an influence on the perception and on the other hand there are the objective event features (e.g. duration). Which of the selected factors shown in Figure 6 actually have an influence on the perceived event features is determined via Mann-Whitney-U-tests. Table 2 shows the corresponding results with the related effect sizes Cohen's d. It is defined as the difference between two means divided by the square root of their average variance (Bortz & Döring, 2006: p. 606). The gender of the participants causes a medium effect size (Bortz & Döring, 2006: p. 606) on both of the relevant features. Males rate the perceived features better than females. Furthermore, students with a higher prior knowledge in particle physics show a more positive rating of “challenge and comprehension” with a medium effect size and of “authenticity” with a small effect size. For the type of the measurement there is only a recognizable effect on “challenge and comprehension”. This is not surprising, due to the fact that the LHC measurements are more difficult in comparison to the LEP measurements.

Table 2: Selected factors influencing the relevant perceived event properties

			Challenge and comprehension			Authenticity		
		N	Mean	Standard deviation	Cohen's d	Mean	Standard deviation	Cohen's d
Gender	Female	≈ 80	2.17	0.85	**0.52****	2.62	0.62	**0.40****
	Male	≈ 310	2.61	0.83		2.89	0.67	
Prior know-ledge	Little	≈ 210	2.28	0.82	**0.66****	2.76	0.65	**0.22***
	Medium to high	≈ 180	2.81	0.80		2.91	0.67	
Type of measure-ment	LHC	≈ 255	2.35	0.87	**0.69****	2.80	0.66	**ns**
	LEP	≈ 120	2.91	0.73		2.92	0.68	

*significant difference between the groups (t-test and U-test) with $p < 0.05$;
*significant difference between the groups (t-test and U-test) with $p < 0.01$;
ns: not significant

Conclusions and outlook

The participants' assessment via the perceived event features indicates that the Particle Physics Masterclasses are much appreciated by the students (cf. Figure 5). The comparison of the physics interests between “experimental group” and “control group” in class 10 shows a larger interest of the Masterclass' participants at the pre-test time. This difference disappears over the 6 to 8 week period. This corresponds to the expectation that one-time events like Masterclasses have only short-term effects on the students' interests. Recent studies of other one-time events show similar results (e.g. Engeln, 2004; Pawek, 2009). It implicates the question, if such interest differences appear for all the groups of Masterclass' participants (cf. Figure 3), which are still under study. Another question is to find a more detailed explanation for this interest difference between “experimental” and “control group”.

The investigation of the influence of the perceived event features shows that “authenticity” as well as “challenge and comprehension” are important properties. Some selected factors which are influencing these perceived event features were illustrated. The effect of the participants' prior knowledge in particle physics, might indicate that a specific preparation of the event in physics lessons could be helpful. Especially concerning the objective event features there should be further factors identified, which have an influence on the perceived event features and thus consequently could improve the effect of the Masterclasses.

REFERENCES

Bilow, U., Jende, K., Kobel, M. & Pospiech, G. (2011). Das Konzept “Masterclass” – Schüler beschäftigen sich mit dem LHC. In *Praxis der Naturwissenschaften – Physik in der Schule*, 60(2), 22–28.

Bortz, J. & Döring, N. (2006). *Forschungsmethoden und Evaluation.* Heidelberg: Springer Verlag.

Engeln, K. (2004). *Schülerlabors: authentische, aktivierende Lernumgebung als Möglichkeit, Interesse an Naturwissenschaft und Technik zu wecken.* Berlin: Logos-Verlag.

Gedigk, K., Glück, A. & Kobel, M. (2011). Netzwerk Teilchenwelt – Ein mobiler Lernort für Teilchenphysik. *Praxis der Naturwissenschaften – Physik in der Schule*, 60(2), 29–33.

Hoffman, L., Häußler, P. & Lehrke, M. (1998). *Die IPN-Interessenstudie.* Kiel: IPN.

Johansson, K. E., Kobel, M., Hillebrandt, D., Engeln, K. & Euler, M. (2007). European particle physics masterclasses make students into scientists for a day. In *Physics Education*, 42(6), 636–644.

Krapp, A. (1992). Das Interessenkonstrukt. In Krapp, A., Prenzel, M. (Eds.), *Interesse, Lernen, Leistung* (297–329). Münster.

Krapp, A. (2006). Interesse. In Rost, D. H. (Ed.), *Handwörterbuch Pädagogische Psychologie* (280–290). Weinheim: Beltz Verlag.

Pawek, C. (2009). *Schülerlabore als interessefördernde außerschulische Lernumgebung für Schülerinnen und Schüler aus der Mittel- und Oberstufe* [Dissertation]. Christian-Albrechts-Universität zu Kiel.

Rudolf, M. & Müller, J. (2012). *Multivariate Verfahren.* Göttingen: Hogrefe Verlag.

ANNEX

Table 3: The relatively stable and the changeable interest variables (answer options: (0) I totally disagree – (4) I totally agree)

Variable	**Examples for Items**	**Number of Items**	**Cronbach‘s α**
Interest in physics as subject	I enjoy physics lessons.	4 Items	$\alpha = .861$
Self-Concept in physics	I don‘t have talent for physics.	4 Items	$\alpha = .880$
Interest in physics as profession	I can imagine to work in a profession, which has something to do with physics.	4 Items	$\alpha = .914$
Interest in doing particle physics in free time	I will spend more free time on particle physics.	4 Items	$\alpha = .862$
Interest in being a part of the network	I plan to get involved in the “Network Particle World”.	6 Items	$\alpha = .898$

Table 4: The different particle physics interest dimensions (answer options: my interest is (0) very low – (4) very big) and of the perceived event features (answer options: (0) I totally disagree – (4) I totally agree)

Variable	**Dimensions**	**Examples for Items**	**Number of Items**	**Cronbach's α**
Interest in particle physics	Contents	what are the fundamental building blocks of matter; what really is the "Higgs"	6 Items	$\alpha = .881$
	Context of research	how research at CERN is organized; which phenomena scientists still can't explain	7 Items	$\alpha = .835$
	Activities of researchers	how physicists at CERN discuss measurement results; how experiments at CERN are performed	5 Items	$\alpha = .877$
Perceived event features	Challenge and comprehension	The introductory presentation was too complicated for me; The aim of the measurement was clear to me.	7 Items	$\alpha = .886$
	Support and atmosphere	I liked the working atmosphere during the measurement; I felt that the tutors were helpful.	5 Items	$\alpha = .846$
	Authenticity	I got a feeling, how research is conducted. Today I learnt something about the aims of physical research.	5 Items	$\alpha = .786$
	Organization and duration	The introductory presentation took too long for me; I would have liked to identify fewer events during the measurement.	4 Items	$\alpha = .774$
	Fit between the event parts	I felt prepared for the measurement through the event identification exercise.	4 Items	$\alpha = .826$

Kerstin Gedigk
Gesche Pospiech
Professur Didaktik der Physik, TU Dresden, Germany

Michael Kobel
Institut für Kern- und Teilchenphysik, TU Dresden, Germany

Scientia in educatione 8(Special Issue), 2017
p. 182–190
ISSN 1804-7106

Coding Scheme for Assessment of Students' Explanations and Predictions

Mihael Gojkošek, Gorazd Planinšič, Josip Sliško

Abstract

In the process of analyzing students' explanations and predictions for interaction between brightness enhancement film and beam of white light, a need for objective and reliable assessment instrument arose. Consequently, we developed a coding scheme that was mostly inspired by the rubrics for self-assessment of scientific abilities. In the paper we present the grading categories that were integrated in the coding scheme, and descriptions of criteria used for evaluation of students work. We report the results of reliability analysis of new assessment tool and present some examples of its application.

Key words: coding scheme, assessment, rubrics, explanation, prediction.

INTRODUCTION

Fundamental features of scientific work in physics are building explanations and on them based testable predictions (Giere, 1997). Therefore, in order to learn science by doing, students should be involved in authentic scientific tasks that include construction of explanations and predictions. Especially students, who are proficient in science, should be able to generate and evaluate scientific evidence and explanations (Duschl, Schweingruber & Shouse, 2007).

More than 600 high-school and university students from Slovenia and Czech Republic were tested during several phases of the extended research on students' ability to construct explanations and predictions for an unknown physics phenomenon. Consequently, the need for robust and reliable assessment tool arose. In this paper we present the process of development of the coding scheme that was used to evaluate the quality of students' explanations and predictions. The paper also addresses the reliability of the coding scheme and demonstrates some examples of its application.

THEORETICAL FRAMEWORK

In the process of development of the coding scheme we were mainly inspired by previous work of Eugenia Etkina and her co-workers. They have developed the tasks and rubrics for formative self-assessment in order to help students to perform better and thus develop scientific abilities (Etkina et al., 2006). Their rubrics are based on cognitive apprenticeship theory and address 7 areas of scientific abilities that scientists use when they construct knowledge and solve problems. These areas include the abilities (1) to represent information in multiple ways, (2) to design and conduct an observational experiment, (3) to design and conduct a testing experiment, (4) to design and conduct an application experiment, (5) to collect and analyze experimental data, (6) to engage in divergent thinking, and (7) to evaluate models, equations, solutions, and claims. Each of 7 rubrics consists of multiple categories that assess specific subabilities (e.g. "Is able to make a reasonable prediction based on a hypothesis."). Each category is further supplemented with detailed description of qualitative criteria that one should possess to be classified in one of four grading levels: "Missing", "Inadequate", "Needs some improvement" and "Adequate". Rubrics for assessment of scientific abilities were later used in several other studies (e.g. Etkina, Karelina & Ruibal-Villasenor, 2008; Etkina et al., 2009) and turned out to be a highly efficient tool. Although the purpose of our assessment differed from the Etkina's, we found the basic form of the rubrics very useful. We have re-designed the set of categories (subabilities) included in rubrics and adapted the criteria descriptions to best fit our needs.

RESEARCH INSTRUMENTS

BRIGHTNESS ENHANCEMENT FILM (BEF)

Brightness enhancement film is an interesting optical element that can be used in several demonstrational experiments suitable for introductory optics course (Planinšič & Gojkošek, 2011). It is one of the thin transparent foils from the backlight system in LCD monitors and can be easily obtained by dismounting any used monitor. The main advantages of using BEF in demonstrational experiment are a) it is an unknown element to vast majority of students and experts, and b) its structure cannot be seen with naked eye.

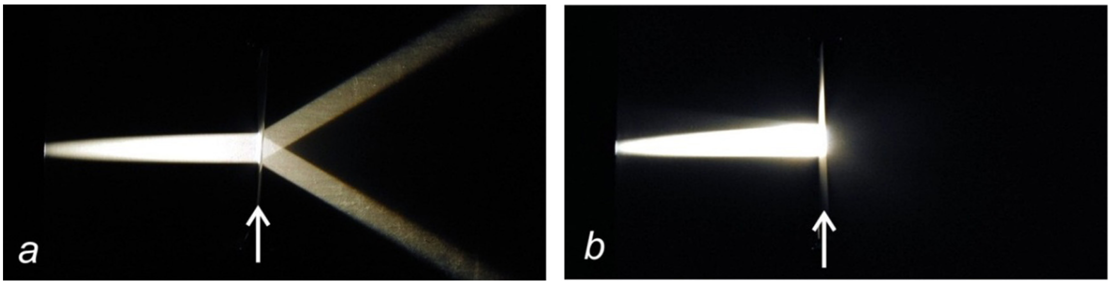


Figure 1: a) The split of the light beam incident perpendicularly to one side of the film, and b) the reflection of the light beam incident perpendicularly to the other side. The arrows show the position of the brightness enhancement film

We integrated two demonstrational experiments with BEF in our testing procedure. Both experiments include a beam of white light (produced by a flashlight) incident perpendicularly to the sides of the film. On one side, the beam of light is split into two symmetrical beams (Figure 1a), while the beam incident perpendicularly to the other side of the film is mostly reflected into the direction of origin (Figure 1b).

The structure of the film can be easily revealed using the school microscope. A magnified cross-section shows that BEF is flat on one side and has microscopic prismatic ridges with the apex angle of approx. 90° on the other side (Figure 2).

Now we can also explain observed outcomes of both demonstration experiments. Light incident perpendicularly to the prismatic side of BEF is refracted in two directions — depending on which side of the prisms the beam strikes (Figure 3a). The light beam incident perpendicularly to the flat side of BEF undergoes double total internal reflection and returns back into the original direction (Figure 3b).

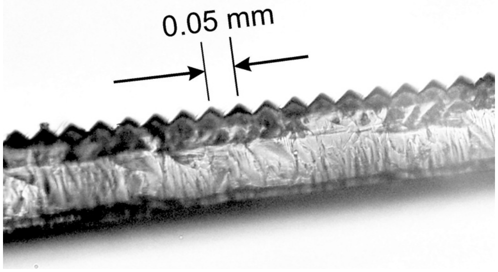


Figure 2: Cross-section of the brightness enhancement film under the microscope reveals prismatic structure

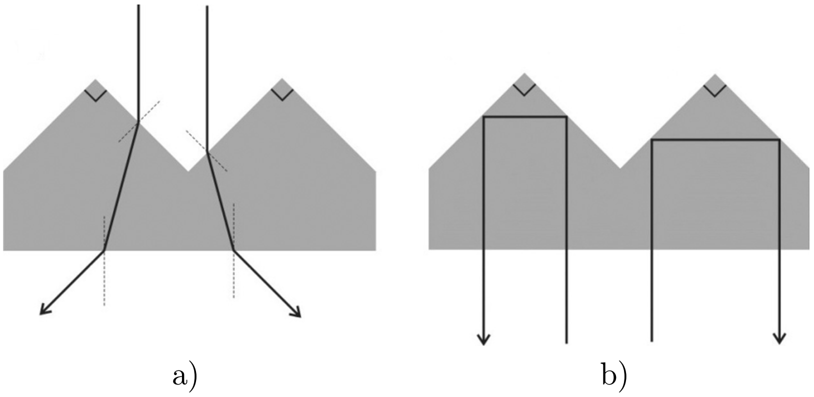


Figure 3: a) Double refraction of the light beam incident on the prismatic ridges, and b) double total internal reflection of the light beam incident perpendicularly to the flat side of BEF

Note that these demonstrational experiments can be combined into two different two step sequences, depending on which experiment is first shown to students. We named them split-reflection (or shorter SR) task sequence (when first the split of light beam was shown to students and then the reflection) and reflection-split (RS) task sequence (when first experiment demonstrated the reflection and second the split).

Foil test

Students were tested with foil test, which was designed by our research group. One part of the foil test was two demonstrational experiments with the BEF described above. First, a teacher showed students one of both experiment (split in SR and reflection in RS task sequence). Then they were asked to construct one or more explanations for interaction of light beam and the BEF on the basis of observed outcome. We encouraged them to present their explanations verbally (text description) and graphically (sketch). Additionally, students had to name optical phenomenon/a, that is on their opinion involved in observed experiment.

Next, students were informed about the second experiment, in which light beam will be incident perpendicularly to the other side of the BEF. They were asked to construct a prediction for experimental outcome on the basis of their previously proposed explanation. Again, their prediction should consist of verbal and graphical part. Teacher later performed second demonstrational experiment (reflection in SR and split in RS task sequence) and asked students, weather their prediction agrees with observed outcome. Finally, students had one more opportunity to construct the improved explanation compatible with the outcomes of both demonstrational experiments.

Lawson's Classroom Test of Scientific Reasoning

As a reference test, Lawson's Classroom Test of Scientific Reasoning (CTSR) was used. A 24-item multiple-choice version of the test was translated into Slovene and used to classify students as concrete-operational, transitional and formal-operational reasoners according to their scores.

Development of coding scheme

Purpose

Previous research showed that majority of students is not able to reveal the actual structure of the BEF on the basis of two demonstrational experiments. Even more, the proportion of those who manage to do so remains low (less than 5 %) even if students are previously involved in pedagogical activity with macroscopic prism and laser ray-box (Gojkošek, Sliško & Planinšič, 2013). Therefore, we wanted to construct a reliable and objective tool for assessment of the quality of students' explanations regardless of their (mis)match with the actual structure of the BEF. Note that observed experimental outcomes can also be explained e.g. with suitable arrangement of reflecting surfaces. Our goal was to develop a set of categories, with which students' explanations and predictions could be easily assessed, and would allow obtaining overall quality grade and further calculation of students' average success.

GRADING CATEGORIES

Our coding scheme consists of three main parts that are formulated for assessment of initial explanation, prediction and improved explanation, respectively. Each part further consists of 4 or 5 categories that assess students' abilities that are needed to solve the task successfully. Assessment categories are presented in Table 1.

Table 1: Categories for assessment of initial/improved explanation and prediction

Initial explanation
Graphical representations
Verbal representations
Correct use of physics
Consistency between outcomes predicted by explanation and observed outcomes
Number of different models
Prediction
Graphical representations
Verbal representations
Consistency with initial explanation
Ability to evaluate agreement of prediction and observed outcome
Improved explanation
Graphical representations
Verbal representations
Correct use of physics
Addressing asymmetry
Consistency between outcomes predicted by explanation and observed outcomes

DEVISING CODE DESCRIPTIONS

After selection of grading categories included in our coding scheme, we devised detailed descriptions of codes. We decided to keep 4-level coding scale used by Etkina et al. as well as descriptive names of grading levels: 0-Missing, 1-Inadequate, 2-Needs some improvement and 3-Adequate. Descriptions of students' work that merit a particular grading level can be found below.

GRADING CATEGORIES FOR INITIAL EXPLANATION

In category "graphical representations", basic drawing elements of the sketch were assessed. We were looking for the structure of the foil (its cross-section), light rays and majority of labels. If these were present, sketch was coded with 3, while the sketch without labels was coded with 2. Any other sketch was coded with 1 and no sketch with 0.

Also in the category "verbal representations", we expected from students to describe foil structure and name involved optical phenomenon. When both included, code 3 was assigned, while for one of them code 2 was used. Other verbal descriptions were considered as "inadequate" and no text was coded with "missing".

When assessing correct use of physics, both graphical and verbal parts of explanation were considered. When optical phenomenon was applied without mistakes, code 3 was used. Misapplication of the phenomenon was coded with 2. Typical students' mistakes include split of the light beam by diverging lens or diffraction grating and total internal reflection of the light incident perpendicularly to the inner surface of a medium. Confusing, contradictory or incomprehensible application of optical phenomenon (e.g. "lens reflects light") were coded with 1 and when no optical phenomenon was included in explanation code 0 was assigned.

We also assessed the consistency between outcomes predicted by explanation and observed outcomes. Particular attention was devoted to the direction of incident and outgoing light rays. If explanation and observed result were consistent, code 3 was assigned, while discrepancy between them was coded with 2. When student's explanation failed to reproduce the main experimental result (split or reflection) code 1 was used, while code 0 was given to explanations that had nothing in common with observed experimental result.

In the grading category "number of different models", two or more explanations that employed different optical phenomenon merit code 3. When the same phenomenon was applied in several explanations, code 2 was assigned. One explanation was coded with 1 and no explanation with 0.

Grading categories for prediction

In assessment categories "graphical and verbal representations", evaluation criteria for prediction were the same as for initial explanation coding. Next grading category assessed consistency between prediction and initial explanation. Prediction that was consistently derived from previously proposed explanation was coded with 3. Inconsistent derivation from initial explanation merit code 2, while any other prediction was coded with 1 and no prediction with 0.

Grading category "ability to evaluate agreement of prediction and observed outcome" assessed students' report about (mis)match of predicted and observed outcome of second experiment. Reasonable decision about agreement/disagreement was coded with 3, while code 2 was assigned when one made a decision about agreement/disagreement that evaluator was unable to judge due to imprecise prediction. When this decision was clearly incorrect, code 1 was assigned, while no agreement assessment was coded with 0.

Grading categories for improved explanation

Similar to previous grading, in assessing graphical representations we were looking for structure of the film, light rays describing both experimental results and majority of labels. Sketch that included all these elements was coded with 3. Film's structure and light rays for both experiments were enough for code 2, while the sketch without one of these elements was coded with 1. For no sketch code 0 was assigned.

Category "verbal representations" addressed presence of verbal description of film's structure and optical phenomena involved in both experiments. When all these elements were present, explanation was coded with 3. If only description of the structure or only optical phenomena was present, or there were both for explanation of just one experiment, code 2 was assigned. Every other verbal explanation was coded with 1, and code 0 was used when no text was present.

For assessment category "correctness of physics" we used the same criteria as for initial explanation coding. With category "addressing asymmetry" we assessed the way in which asymmetrical behavior of the BEF was explained. Code 3 was assigned when film's asymmetrical properties were explained in consistent way. If asymmetry was provided through mechanical composition of two optical elements, explanation was coded with 2. Code 1 was used when asymmetry was granted but not explained, and code 0 was assigned when asymmetry was not addressed.

In improved explanation, we also assessed consistency between outcomes predicted by explanation and observed outcomes. Similar to coding of initial explanation, code 3 was assigned when explanation and observed results were consistent. Code 2 was used when direction of incident/outgoing light beams were misinterpreted, while code 1 was assigned to explanatory models that failed to reproduce main experimental outcomes — split and reflection of incident light beams. If incident or outgoing light beams were not drawn, code 0 was assigned.

Analysis of reliability

Tests of 197 students from Slovenian high-schools were assessed with described coding scheme. Approximately 20 % of all tests were independently evaluated by two researchers. Their coding matched in 90 % of all cases. Also inter-rater agreement coefficients like Cohen's kappa ($\kappa = 0.87$) and Pearson's correlation coefficient ($r = 0.92$) indicate high reliability of this assessment tool.

Combined grades

As mentioned, one of our goals was to obtain combined grades for overall quality of students' explanations and predictions. Before that, some assumptions needed to be taken into account. First, we assumed scale nature of grading levels. As a consequence of that assumption, one can summarize and calculate average grades for different categories. And secondly, weights suitable to importance of each grading category needed to be set. Since in our opinion all addressed categories play similarly important role in overall quality of explanations and predictions, all weights have been set to 1. Combined grade for the quality of initial explanation is consequently calculated as a sum of grades of all five categories that assess this explanation. Similarly combined grades for the quality of prediction and improved explanation are calculated by summarizing grades of individual categories.

Some examples of application and obtained results

Using grades achieved in single grading category and combined grades, we were able to compare different groups of students according to scientific reasoning ability level (concrete/transitional/formal) and task sequence they were involved in (SR/RS). Our results suggest that difference between concrete-operational and formal-operational reasoners is statistically significant for some categories and insignificant for others. An example of grading category in which this difference was among highest is correct use of physics in improved explanation. Average grades achieved in this category can be found in table 2. Mann-Whitney nonparametric U-test revealed that difference between concrete- and formal-operational groups are highly statistically significant in both, SR and RS task sequences ($U = 50$, $p = 0.002$, and $U = 137$, $p = 0.001$, respectively). On the other hand, in the category "number of different models" no significant difference between these groups was observed ($U = 126$, $p = 0.31$ in SR, and $U = 276$, $p = 0.75$ in RS task sequence).

Table 2: Average grades achieved in the category "correct use of physics" in improved explanation and "number of different models" in initial explanation

	split-reflection (SR)		reflection-split (RS)	
	concrete thinkers	formal thinkers	concrete thinkers	formal thinkers
improved explanation: verbal representations	1.4	1.8	1.2	1.5
initial explanation: number of different models	1.3	1.2	1.2	1.2

Table 3: Average combined grades for the quality of improved explanation

	split-reflection (SR)		reflection-split (RS)	
	concrete thinkers	formal thinkers	concrete thinkers	formal thinkers
improved explanation: combined grade for quality	5.7	8.5	4.1	7.4

Significant difference between concrete-operational and formal-operational thinkers was found also by comparison of combined grades for the quality of improved students' explanations (Table 3). Again, Mann-Whitney U-test was used to calculate the significance of these differences in SR ($U = 55.5$, $p = 0.010$) and RS task sequences ($U = 115.5$, $p = 0.000$).

CONCLUSIONS

In our study, high-school students' ability to construct explanations and on them based predictions was taken under examination. For that purpose students were involved in testing procedure with two demonstrational experiments, in which interaction between brightness enhancement film (BEF) and beam of white light was presented. Students were asked to propose possible explanations for observed interaction and to predict the outcome of the second experiment. During the analysis of students' tests the need for objective assessment tool arose. We decided to develop a coding scheme based on the rubrics for assessment of scientific abilities (Etkina et al., 2006, 2009; Etkina, Karelina & Ruibal-Villasenor, 2008) that would allow obtaining reliable grades for the quality of students' explanations and predictions.

Developed coding scheme consists of three separate rubrics that assess students' initial explanation, prediction and improved explanation, respectively. Each rubric further consists of grading categories that assess students' work in explanation and prediction formation. Four-level grading scale is used to evaluate each grading category. Categories are equipped with detailed descriptions of essential elements that need to be present to merit a particular level. Combined grades for the quality of students' explanations and predictions are obtained by summarizing grades of categories in one rubric.

We conclude that rubric-like coding scheme is an effective tool for assessment of students' explanations and predictions. Developed coding scheme shows high level of reliability assessed through inter-rater agreement coefficients. Under some assumptions, grading categories of the coding scheme can be used to evaluate overall quality of students' explanations/predictions and their average performance.

ACKNOWLEDGEMENT

Authors would like to thank Bor Gregorčič for the help with evaluation of students' tests, and Eugenia Etkina for helpful discussion in the process of development of coding scheme.

REFERENCES

Duschl, R. A., Schweingruber, H. A. & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, DC: National Academies Press.

Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D. T., Gentile, M., Murthy, S., Rosengrant, D. & Warren, A. (2006). Scientific abilities and their assessment. *Phys. Rev. Spec. Top.*, 2, 020103.

Etkina, E., Karelina, A. & Ruibal-Villasenor, M. (2008). How long does it take? A study of student acquisition of scientific abilities. *Phys. Rev. Spec. Top.*, 4, 020108.

Etkina, E., Karelina, A., Murthy, S. & Ruibal-Villasenor, M. (2009). Using action research to improve learning and formative assessment to conduct research. *Phys. Rev. Spec Top.*, 5, 010109.

Giere, R. N. (1997). *Understanding scientific reasoning.* 4th edition. Orlando: Harcourt Brace College Publishers.

Gojkošek, M., Sliško, J. & Planinšič, G. (2013). Do learning activities improve students' ability to construct explanatory models with a prism foil problem? *CEPS Journal*, 3(3), 9–28. Available at http://www.cepsj.si/pdfs/cepsj_3_3/cepsj_pp_9-28_Gojkosek.pdf

Planinšič, G. & Gojkošek, M. (2011). Prism foil from an LCD monitor as a tool for teaching introductory optics. *Eur. J. Phys.*, 32(2), 601–613.

MIHAEL GOJKOŠEK
GORAZD PLANINŠIČ
Faculty of Mathematics and Physics, University of Ljubljana, Slovenia

JOSIP SLIŠKO
Facultad de Ciencias Fisico Matematicas, Benemerita Universidad Autonoma de Puebla, Mexico

Scientia in educatione 8(Special Issue), 2017
p. 191–198
ISSN 1804-7106

A Hands-on to Teach Colour Perception: The Colour Vision Tube

Claudia Haagen-Schützenhöfer

Abstract

One basic concept for understanding colour phenomena is the concept of vision. Although vision seems to be quite a natural and simple thing, students are often not familiar with the mechanism behind perceiving objects or even “the colour of objects”. This contribution introduces a simple hands-on experiment, the Colour Vision Tube. The Colour Vision Tube facilitates the experience of seeing “coloured” objects illuminated with other than white light sources. These experiences support students in understanding the relevance of the illuminating light and the conception of selective reflection for colour vision.

Key words: basic optics, colour, vision.

INTRODUCTION

Colour phenomena are usually fascinating. However, it is frequently quite challenging for students to explain such phenomena based on adequate scientific concepts. This contribution focuses on body colour phenomena. After instruction of basic optics, students still believe the colour impression they get from an object is a fixed property of this object. (Andersson & Kärrqvist, 1983; Driver, Guesne & Tiberghien, 1985; Fetherstonhaugh & Treagust, 1992; Viennot & de Hosson, 2012). Although they are mostly able to reproduce the laws of colour mixing, they can hardly account for colour impressions produced by objects illuminated with other than white light sources. We developed a hands-on experiment, the Colour Vision Tube, which can be easily used in class to demonstrate such colour effects.

THEORETICAL BACKGROUND

Students' ideas about vision have been investigated thoroughly and show students' difficulties in explaining the visibility of objects based on light emitted by a source and reflected by the object into the observer's visual system (cf. Figure 1, physicists' model).

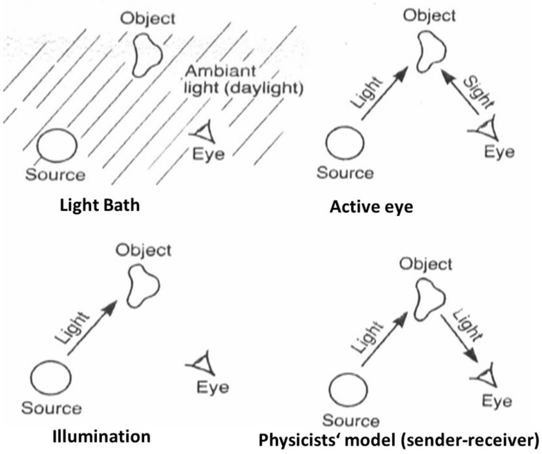


Figure 1: Students' conceptions on vision (categories based on (Guesne, 1985))

Without a basic concept of vision, it seems to be difficult to develop scientifically adequate ideas concerning colour and coloured objects. As a result, it is frequently believed that colour is a fixed property of an object, as mass is for example. Empirical research shows that misconceptions about colour are not only present among students but also among many adults (Martinez-Borreguero et al., 2013).

Feher & Meyer (1992: p. 505–520) give a summary of the most frequently held conceptions about colour vision:

1. Coloured light mixes with the colour of the object,
2. coloured light is dark and makes the object darker,
3. coloured light gives the colour to the object and
4. coloured light has no effect on the object.

Conventional instruction is usually not successful in transforming these conceptions into adequate physical concepts about vision and colour (Andersson & Kärrqvist, 1883; Martinez-Borreguero et al., 2013). From conceptual change theory it

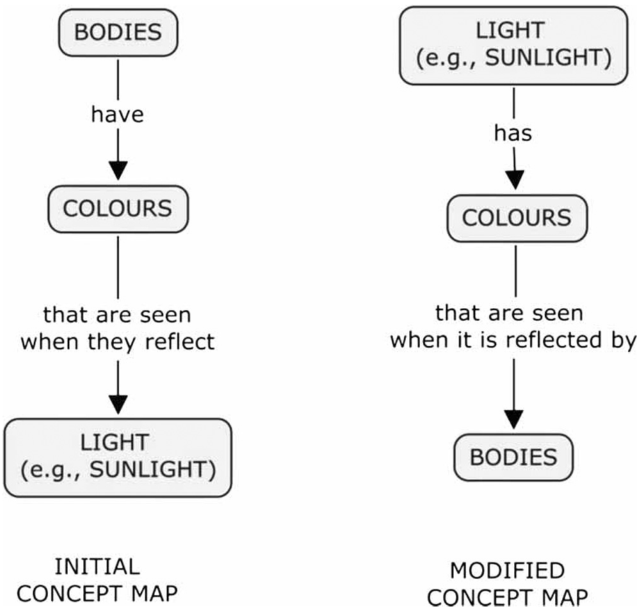


Figure 2: Concepts about colour phenomena (left: frequently held student conception; right: "new", scientifically sound concept) (Martinez-Borreguero et al., 2013)

is known that conceptions tend to be extremely stable as they have proved to be viable in daily life in uncountable occasions (Posner et al., 1982). Thus, students do not feel the necessity to change their ideas; they frequently hold the idea that bodies have a permanent colour that can be seen when they are illuminated (cf. Figure 2, left). This theoretical background explains quite well why especially colour issues are difficult for students. In their daily lives they are predominantly in situations where their surroundings are illuminated by some kind of white light sources.

One major issue of discussion within conceptual change is the question how to address students' misconceptions in order to trigger conceptual change. Conceptual change research has not come to empirically grounded solutions on this issue, yet. Posner et al. (1982: p. 211–227), however, suggested a number of broadly accepted requirements characterising new concepts presented to students. To support conceptual change, they recommended that students do not only need to be dissatisfied with their current conceptions but the new conceptions introduced need to be intelligible, plausible, and fruitful. The Colour Vision Tube was thought to provide a variety of evidences that widen students' ideas about colour vision. Their conceptions about colour being a fixed property of an object (cf. Figure 2, left) should be reorganised in the following way: light has colour(s), objects selectively reflect them and the composition of the light received by our visual system creates a certain colour impression (cf. Figure 2, right).

Research Aims & Questions

The overall aim of this project was to promote students' understanding of "seeing colours". The main idea was to create a learning environment that makes students familiar with the experience of observing "differently coloured objects" illuminated by differently coloured light. Our intention was to create a hands-on that is easy to construct and also easy to handle in the classroom and above all, a hands-on that functions as learning environment which can be individually manipulated by students. The purpose of the evaluation conducted was to analyse learning effects triggered by the use of the Colour Vision Tube. Our main research questions were:

1. Does the use of the Colour Vision Tube promote a sender-receiver model of vision?
2. Does the use of the Colour Vision Tube promote students' understanding of selective absorption and reflection as basic condition for body colour phenomena?

METHODS

A micro-teaching intervention based on the Colour Vision Tube was designed to be used in semi-structured student interviews. The intervention was aimed at students after their basic instruction in optics in year 8[1]. The students of our sample ($N = 21$, 9 female & 12 male) were aged 13 to 15 years. They were randomly selected: they had different school carriers and learning histories in physics, were in different types of schools in different areas of Austria. In order to avoid having a sample not representing the "typical Austrian high school student" at this age group, we also wanted to find out about their attitude towards physics and learning of physics. For this purpose we used the concept of self-efficacy in physics – following the scales of PISA 2000. The students of our sample showed a mean self-efficacy in physics $m = 2.39$[2] (SD = 0.73). This quite well fits the data of the Austrian PISA sample 2000 with a mean self-efficacy of $m = 2.37$ (SD = 0.84) (Kunter et al., 2002).

In the first part of the interview the students filled in the PISA scales on self-efficacy and some other general data. Then they were given test items on colour vision (Herdt, 1990). After that they worked with the Colour Vision Tube following the P(redict) O(bserve) E(xplain) structure (White & Gunstone, 1992). Finally, the students were asked to do some transfer tasks and fill in test items. The interviews were led by trained interviewers.

The data collected from the interviews were analysed concerning the lines of argumentations students used to explain colour phenomena before and after the short POE intervention with the Colour Vision Tube. The categories underlying the analysis were taken from literature. The categories about students' conceptions on colour vision were based on Feher & Meyer (1992). As we did not find any students' statements relating to the idea that coloured light is dark and makes the object darker, this category was omitted. The categories on conceptions on vision also had to be modified (Guesne, 1985). An additional category "reflection" was created which subsumed all student utterances that mentioned that the disc in the vision tube reflected light, but that did not contain any hints that this reflected light (partly) entered the visual system of the observer.

THE INTERVENTION WITH THE COLOUR VISION TUBE

The Colour Vision Tube is a hands-on made of a tube[3] which is closed at one end with a disc made of differently coloured segments (cf. Figure 3). In the middle of the

---

[1] In the Austrian educational system basic optics (including colour phenomena) is part of the year 8 Physics curriculum. Wave optics is part of the year 10 curriculum.

[2] Self-efficacy runs from 1 to 4. 1 stands for high self-efficacy.

[3] The tube is about 25 cm long and 8 cm in diameter. It is made of insulating material for heating pipes.

Figure 3: The Colour Vision Tube (CVT)

tube, there is a light inlet just big enough to insert the light source. As light source we used a modified version of the colour mixer by Planinšič (2004: p. 138), a quite easy to build device based on RGB colour addition of LEDs. The open end of the tube serves as peephole for the observer. When students look through this peephole while the tube is illuminated with differently coloured LEDs, they can experience the effect of different illumination on the "body colour" they perceive.

During the intervention phase with the Colour Vision Tube, the students had to work successively on two predictions:

1. What will happen if we block the hole? (first POE cycle)
2. What will happen if we illuminate the Colour Vision Tube with red light? (second POE cycle)

The first prediction cycle was meant to initiate learning processes on a physical concept of vision based on a sender-receiver model (cf. Figure 1). The second cycle was based on the idea that the "colour of an illuminated object" depends on the illuminant. So after observing the Colour Vision Tube illuminated with red light, the students had the opportunity to explore the effects of differently coloured illuminants (cf. Figure 4).

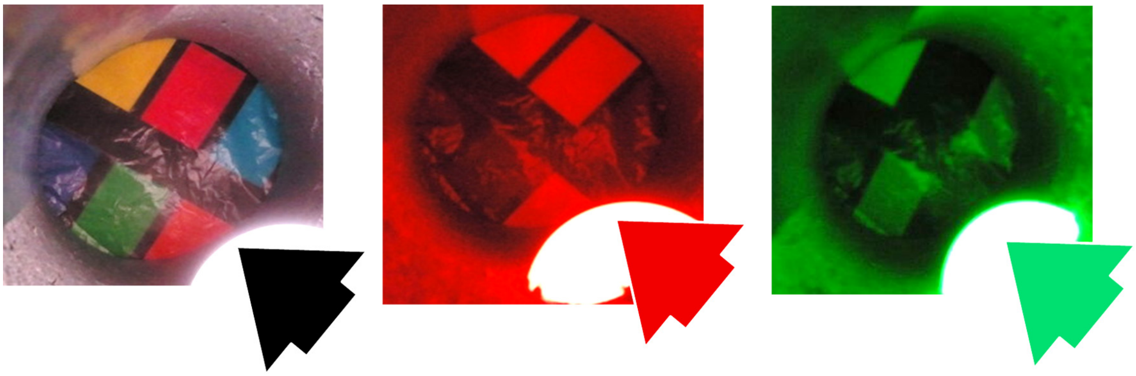


Figure 4: The inside of the Colour Vision Tube illuminated with white, red and green light

Selected results

The data collected during the first POE cycle showed that the majority of students firstly used common sense arguments to explain why they were able to see the coloured disc at the end of the tube only as long as the light inlet was not blocked. Most students used the concept of illumination without considering the necessity of

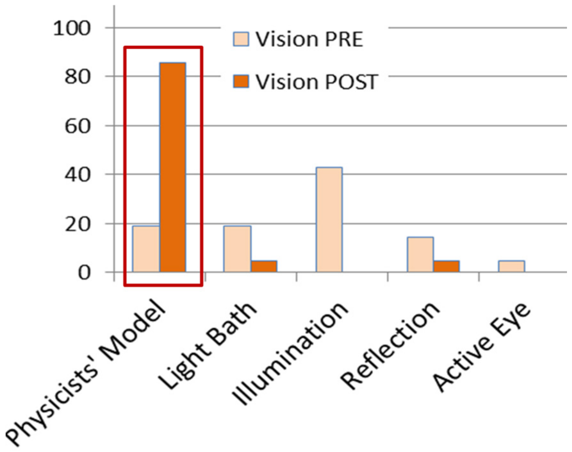


Figure 5: Students' ideas concerning vision before and after the CVT-intervention in percent

light from the disc entering the eye of the observer (cf. Figure 5). After the first POE cycle the majority of the students did not only know that light is necessary for vision, but they also identified the light source (the illuminant), the illuminated object and the eye (receiver) as essential components for vision.

The second POE cycle focused on colour vision, on the apparent colour of objects illuminated with light sources other than white. Most students initially believed that either the colour of the illuminant or a mixture of the colour of the illuminant and the colour of the illuminated object was responsible for the colour they perceived (cf. Figure 6). Only a minority of students held the conception that selective re-emission determines the perceived colour. Similarly, the idea that the apparent colour of an object stays the same independently of the colour of the illuminant, was rarely mentioned.

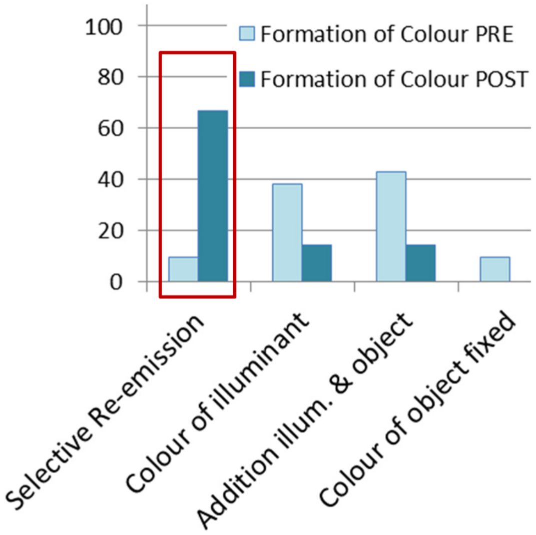


Figure 6: Students' ideas concerning colour vision before and after the CVT-intervention in percent

After the second POE cycle, about two thirds of the students were able to apply the idea that colour impression is not a consequence of the property of objects but a consequence of the interaction between an object and the light illuminating this object (cf. Figure 6). However, a closer analysis showed that they had problems when primary colours of subtractive and additive colour mixing were used at the same time. For example it was easy for them to use the RGB scheme to explain why the blue and green segments[4] of the disc appear to be black when using a red illuminant. On the other hand, most students were not able to account for the fact that yellow and magenta segments[5] appear to be reddish when illuminated with red light, while cyan segments appear to be black.

SUMMARY & CONCLUSIONS

The hands-on we called "Colour Vision Tube" (CVT) is easy to build. Its use in class turned out to be simple and effective. Observations with the CVT support students in experiencing colour characteristics of an illuminated object with varying illuminants (ranging from no illumination at all to white and differently coloured light).

In the prediction-stages of our intervention, most students were not able to verbalize the process of vision based on a physical correct model, nor were they able to explain the physical process of seeing colours adequately. After reinforcing a physicit's model of vision in the first POE cycle, students could experience the effect of different light colours on their perception of objects in a second POE cycle.

They are used to judging the "colour of an object" when illuminated by sunlight or similar light. The lacking experience of illuminants with different colour characteristics seems to hinder students to internalize the concept that colour is not a physical property of an object, but depends on how an object reflects light that reaches it.

The use of the CVT gives students the opportunity to experience the effects of changing light colour on the reflecting behaviour of objects. This seems to support students in developing a relationship between their visual colour sensation, the colour characteristic of an illuminant and the reflection behaviour of the illuminated object.

REFERENCES

Andersson, B. & Kärrqvist, C. (1983). How Swedish pupils, aged 12–15 years, understand light and its properties. *International Journal of Science Education*, 5(4), 387–402.

Driver, R., Guesne, E. & Tiberghien, A. (1985). *Children's ideas in science.* Buckingham: Open University Press.

Feher, E. & Meyer, K. (1992). Children's conceptions of color. *Journal of research in Science Teaching*, 29(5), 505–520.

Fetherstonhaugh, T. & Treagust, D. (1992). Students' understanding of light and its properties: Teaching to engender conceptual change. *Science Education*, 76(6), 653–672.

Guesne, E. (1985). Light. In R. Driver, E Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (10–32). Buckingham: Open University Press.

---

[4] To be more precise: the segments of the disc which appear blue and green when illuminated with white light.

[5] To be more precise: the segments of the disc which appear yellow and magenta when illuminated with white light.

Herdt, D. (1990). *Einführung in die elementare Optik. Vergleichende Untersuchung eines neuen Lehrgangs.* Essen: Westarp-Wissenschaftsverlag.

Kunter, M., Schümer, G., Artelt, C., Baumert, J., Klieme, E., Neubrand, M., Prenzel, M., Schiefele, U., Schneider, W., Stanat, P., Tillmann, K.-J. & Weiß, M. (2002). *PISA 2000: Dokumentation der Erhebungsinstrumente.* Max-Planck-Inst. für Bildungsforschung.

Martinez-Borreguero, G., Pérez-Rodríguez, Á. L., Suero-López, M. I. & Pardo-Fernández, P. J. (2013). Detection of misconceptions about colour and an experimentally tested proposal to combat them. *International Journal of Science Education*, 35(8), 1299–1324.

Planinšič, G. (2004). Color mixer for every student. *The Physics Teacher*, 42, 138–142.

Posner, G., Strike, K., Hewson, P. & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211–227.

Viennot, L. & de Hosson, C. (2012). Beyond a dichotomic approach, the case of colour phenomena. *International Journal of Science Education*, 34(9), 1315–1336.

White, R. & Gunstone, R. (1992). *Probing understanding.* Routledge.

CLAUDIA HAAGEN-SCHÜTZENHÖFER
Institute of Physics, Didactics of Physics, University of Graz, Graz, Austria

sciED
Scientia in educatione 8(Special Issue), 2017
p. 199–206
ISSN 1804-7106

Increasing Physics Teacher Production by Replicating the UTeach Preparation Model and Awarding Noyce Scholarships

Gregory R. Hale, Ramon E. Lopez,
Ann M. L. Cavallo, Erin E. Gonzales

Abstract

In order to improve the production of physics teachers, and high school science teachers in general, at The University of Texas at Arlington, the authors obtained grant funding to offer National Science Foundation Robert Noyce Teacher Scholarships and to support a replication of the successful UTeach science and mathematics teacher preparation program. The Noyce grant was obtained first, and a modest increase in science teacher production was seen. The UTeach replication has been implemented on a four-year schedule, culminating in the establishment of a new student teaching program in January 2014. The combination of a UTeach replication and availability of Noyce Scholarships has UT Arlington poised to improve its science teacher production by an order of magnitude.

Key words: teacher training, teacher preparation, university education, secondary education: upper.

Introduction

The preparation of an adequate number of very well qualified secondary science and mathematics teachers is a well-publicized problem in the United States. In particular, the preparation of physics teachers has greatly lagged the need for highly qualified classroom instructors. The state of Texas, home to the authors, is not immune from this issue. In fact, physics teacher production in Texas (Table 1) is far from in line with what should be expected from a state with a population of over 26 000 000.

Table 1: Physics and other physical science teacher production in Texas, 2006 to 2012

Academic Year	8–12 Physics-Math Teacher Production	8–12 Physical Science Teacher Production	8–12 Physical Science-Math-Engineering Teacher Production	8–12 Chemistry Teacher Production
2006–2007	20	88	NA	49
2007–2008	27	74	3	68
2008–2009	17	56	5	72
2009–2010	31	55	9	60
2010–2011	37	34	8	59
2011–2012	27	24	7	36

While it would be nice to say that our institution, The University of Texas at Arlington (UT Arlington), had been a shining example during this period, we cannot. Our production of teachers in the physical sciences was similarly lacklustre (Table 2).

Table 2: Physics and other physical science teacher production at The University of Texas at Arlington, 2006 to 2013

Academic Year	8–12 Science Teacher Production	8–12 Physics Teacher Production	8–12 Physical Science Teacher Production	8–12 Chemistry Teacher Production
2006–2007	1	0	0	0
2007–2008	2	0	0	0
2008–2009	1	0	0	0
2009–2010*	1	0	0	0
2010–2011	6	0	1	1
2011–2012	5	1	0	0
2012–2013 (partial)	3	0	0	0

*first year Noyce Scholarships awarded at UT Arlington

Author Hale began to explore options for improving secondary math and science teacher production at UT Arlington in late 2006. Soon thereafter, the UT Arlington Provost, Dean of Science and author Hale met with the Dean of Natural Sciences from The University of Texas at Austin (UT Austin) to learn about the UTeach program. Author Hale then visited UT Austin and spoke with UTeach Co-Directors and

Master Teachers about the program. (Coincidentally, author Lopez, then with the Florida Institute of Technology, was visiting UTeach Austin as a seminar speaker at the same time.) Upon learning that a competition would be announced in the coming months for UTeach replication grants, authors Hale and Cavallo began preparing a submission. Author Lopez was hired by UT Arlington in the midst of this process, and he contributed to the preparation prior to his arrival on campus for the 2007–2008 academic year.

To help illustrate why the UTeach teacher preparation approach was attractive to the authors, provided below is a description of the origin of UTeach from the UTeach Austin web site (The University of Texas at Austin, n.d.a).

Beginning in 1997, The University of Texas at Austin set out to effect long-term, systematic change in the way science and mathematics majors were being prepared for careers in secondary math or science education. The Dean of the College of Natural Sciences, Mary Ann Rankin, brought together a group of experienced secondary teachers and administrators and charged them to design an innovative teacher preparation program based on national standards, educational research, and their years of experience in the K-12 setting. As part of a substantially revised approach to teacher education called UTeach, the College of Natural Sciences employs several of the best high school science and math teachers in the state to lead the introductory UTeach courses and coordinate a range of on-going field-based experiences. To reinforce the value of such a career choice for students, the College of Natural Sciences offers a rebate for these introductory courses.

At the same time, the Dean of the College of Education, Manuel Justiz, undertook a major commitment to rebuild and strengthen the College's program in mathematics and science education. Under the leadership of Dr. Jere Confrey, mathematics and science education faculty made the decision to completely revise the professional development courses. They developed a three-course sequence that builds on research on student learning, the examination of standards-based curricula, the study of effective classroom interactions, and the development of models of teaching. Issues of technology use and effective approaches to equitable participation are embedded in all aspects of the program, culminating in students' teaching an entire unit in Project Based Instruction. In addition, the mathematics and science education faculty place students in high-need schools, where they learn firsthand of the needs, challenges and opportunities involved in these settings.

The UTeach program at UT Austin was successfully producing dozens of secondary math and science teachers instead of the low single digits that UT Austin had been producing before 1997. Even more impressive to the authors was the improved longevity that UTeach-prepared math and science teachers were exhibiting. Back in 2006, the data showed that more than 80 % of UTeach Austin prepared teachers were still in the teaching profession after four years (Rankin, 2006). Compared to Ingersoll's data published in 2003 which showed that the four-year retention rate for all teachers was 60%, it seemed that the UTeach approach was not only preparing more teachers, it was producing better prepared teachers (Ingersoll, 2003).

At the same time that the authors were preparing the UTeach replication proposal, funding was also sought from the National Science Foundation's (NSF) Robert Noyce Teacher Scholarship program (National Science Foundation web site, n.d.). From 2008 to 2010, the authors had two Noyce proposals funded. The first was for candidates seeking certification as physics, chemistry or math secondary teachers, and the second covered candidates seeking secondary life science or middle level math and science teacher certification.

METHODS

The NSF Noyce Scholarship grants allowed UT Arlington to offer full tuition scholarships to junior and senior science and math majors preparing for teacher certification, renewable for up to two years of support. In addition, post-baccalaureate candidates could also be supported for one year as they worked towards teacher certification. Scholarships were awarded to math, chemistry and physics teacher certification candidates beginning in 2009. Scholarships were awarded to life science and middle level teacher certification candidates beginning in 2011.

These scholarships were marketed with flyers on our campus, classroom visits by grant personnel in classes where sophomore and junior science and math majors were in high proportion, and flyers at the nearest community college to reach transfer students. Once our UTeach replication was running sophomore level courses (2011-2012 academic year), marketing efforts were also made to particularly target these students.

Authors Hale, Lopez and Cavallo as Co-Directors received a UTeach Replication Grant from the National Math and Science Initiative in September 2009, and the program recruited its first 89 students in the fall of 2010. Between September 2009 and August 2010, the Co-Directors hired the initial UTeach Arlington staff and began revising degree plans and creating new coursework. That is to say, the Co-Directors started to put in place the Elements of Success (The University of Texas at Austin, n.d.b) of a UTeach replication.

- Distinctive Program Identity.
- Cross-College and School District Collaboration.
- Long-Term Institutional and Community Support.
- Compact and Flexible Degree Plans.
- Active Student Recruitment and Support.
- Dedicated Master Teachers.
- Rigorous, Research-Based Instruction.
- Early and Intensive Field Experiences.
- Continuous Program Improvement.

Figure 1: Distinctive program identity: UTeach Arlington logo

Special emphasis was placed on certain elements of success at UT Arlington. For example, the Co-Directors immediately created a UTeach Arlington identity by designing a logo and launching a program web site (http://www.uta.edu/uteach). In addition, contiguous space in the university's oldest science building was allocated to UTeach Arlington. Once renovations were complete, the UTeach Arlington logo (Figure 1) was installed by the entrance to each office, conference room, classroom, and even storage rooms to give UTeach Arlington students the feeling of being at their academic home when they were going to their UTeach classes. To reinforce this sense of identity, UTeach Arlington students are provided with a student lounge, equipped with computers, a scanner, a printer, education journals, and other resources. The lounge is well attended by students looking to get some work done and students that simply want to relax and socialize until their next class starts.

The Co-Directors extended the Dedicated Master Teachers element of success to all UTeach Arlington hires. The first four hires were for a business manager, academic advisor, science master teacher and math master teacher. All four hires proved to be extremely dedicated personnel. All have contributed mightily to the sense of community that UTeach Arlington students experience. The master teachers were veteran classroom teachers who each also had administrative experience. Their expertise and network of colleagues in area school districts proved to be invaluable in continuing to fulfil another UTeach Element of Success — School District Collaboration. Subsequent hires of two master teachers and an accountant proved to be equally strong. All of the UTeach Arlington master teachers and staff are solutions-focused and student-centered.

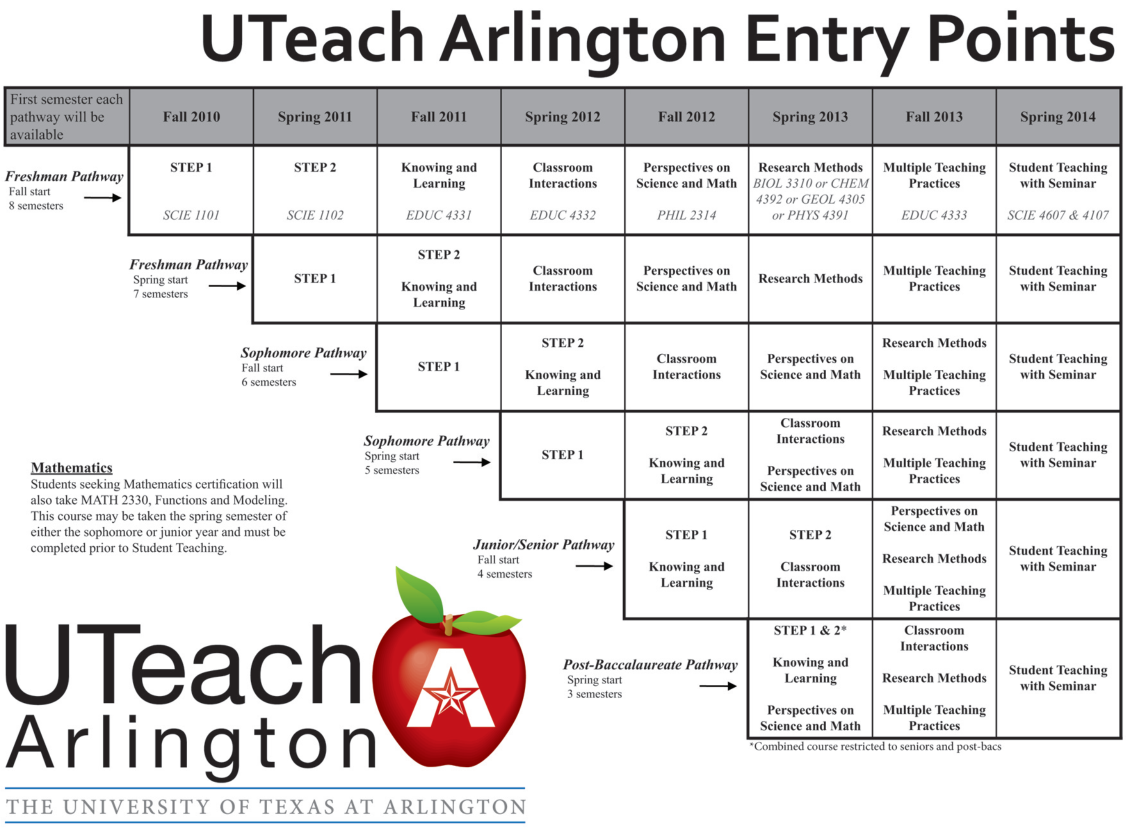
The Active Student Recruitment and Support Element of Success is anchored at UTeach Arlington by the dedicated academic advisor (author Gonzales). The UTeach Arlington academic advisor is dedicated in two senses of the word. Firstly, she only advises UTeach Arlington students. Secondly, she works exceptionally hard to keep UTeach Arlington students on the path to success. To date, author Gonzales has also been responsible for the most effective recruiting strategy. She visits each College of Science freshman and transfer student orientation (mandatory for UT Arlington students) and makes a three-minute pitch to the students and their parents. The presence of the parents during this recruiting pitch appears to be important. When the recruiting pitch mentions a strong job market for math and science teachers and the availability of substantial financial aid, the parents are observed to be paying close attention. The typical result of this recruiting strategy is full sections of the first course in the UTeach sequence. The original master teacher hires, subsequent master teacher hires (also very experienced in the classroom and administration), and subsequent office staff hire have formed a very dedicated and enthusiastic team. Wherever a potential UTeach Arlington student turns for help, he or she will find someone more than willing to resolve his or her questions.

The UTeach Arlington team has also worked hard to ensure that we offer Compact and Flexible Degree Plans. Whether a UTeach Arlington student joins us as a first-time freshman or a transfer student, they will find a pathway through our program already mapped out for them (Figure 2). Our academic advisors also prepare a customized plan for each student, outlining the courses he/she should take each semester until graduation.

As far as Rigorous, Research-Based Instruction is concerned, our pedagogical methods are centered on the learning cycle and its 5E lesson plan implementation. The Master Teachers provide a basic introduction to the Learning Cycle in the STEP 1 and STEP 2 recruitment courses. UTeach Arlington students put this knowledge into field practice in these first two UTeach courses, delivering 5E lessons in the classroom of a mentor elementary or middle school teacher. Subsequent UTeach coursework provides the learning research and educational psychology foundation of the learning cycle, further training in learning cycle teaching methods, and classroom management skills. In all, there are four courses in the UTeach program prior to student teaching that have field experience components. All courses in the UTeach Arlington program are described in Table 3.

Table 3: UTeach Arlington course descriptions

Course Name	Course Description
STEP 1	Introduction to mathematics and science teaching as a career. Discussions include standards-based lesson design and various teaching and behavior management strategies. Fieldwork consists of planning and teaching three inquiry-based lessons to students in grades three to six in local elementary schools. One and one-half class hours a week for one semester; at least ten hours of fieldwork a semester are also required.
STEP 2	Topics may include routes to teacher certification in mathematics, computer sciences, and science teaching; various teaching methods that are designed to meet instructional goals; and learner outcomes. Students develop and teach three inquiry-based lessons in their field in a middle school, and participate in peer coaching. One and one-half class hours a week for one semester; at least twenty hours of fieldwork a semester are also required.
Knowing & Learning	Restricted to students in the UTeach Arlington program. Psychological foundations of learning; problem solving in mathematics and science education utilizing technology; principles of expertise and novice understanding of subject matter; implications of high-stakes testing; and foundations of formative and summative assessment. Three lecture hours a week for one semester; additional hours may be required.
Classroom Interactions	Restricted to students in the UTeach Arlington program. Principles of delivering effective instruction in various formats (lecture, lab activity, collaborative settings); examination of gender, class, race, and culture in mathematics and science education; overview of policy related to mathematics and science education. Three lecture hours a week for one semester; additional hours may be required.
Perspectives on Science And Mathematics	An examination of five notable episodes in the history of science: Galileo's conflict with the Catholic Church, Isaac Newton's formulation of the laws of motion, Charles Darwin's proposal of the theory of evolution by natural selection, the development of the atomic bomb, and the discovery of the double helix structure of DNA. Three lecture hours and one discussion hour a week for one semester.
Research Methods	Primarily a laboratory course where students develop and practice skills fundamental to the scientific enterprise. Research Methods is organized around four independent inquiries that students design and carry out. The course emphasizes the use of mathematics to model and explain both the natural and man-made worlds, and requires a substantial amount of writing. Research Methods emphasizes the development of skills that are directly applicable in teaching secondary science and mathematics (e.g. use of equipment, preparation of lab materials, safety issues, use of technology).
Multiple Teaching Practices	Foundations of project-based, case-based, and problem-based learning environments; principles of project-based curriculum development in mathematics and science education; classroom management and organization of project-based learning classrooms. Three lecture hours a week for one semester with additional fieldwork hours to be arranged.
Student Teaching	Supervised and directed practice in an approved field setting. The student will be assigned based on the cooperating school district calendar. Required seminars will provide students with theory to integrate and apply during residency.



UTeach Arlington Entry Points

First semester each pathway will be available	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012	Spring 2013	Fall 2013	Spring 2014
Freshman Pathway Fall start 8 semesters	STEP 1 *SCIE 1101*	STEP 2 *SCIE 1102*	Knowing and Learning *EDUC 4331*	Classroom Interactions *EDUC 4332*	Perspectives on Science and Math *PHIL 2314*	Research Methods *BIOL 3310 or CHEM 4392 or GEOL 4305 or PHYS 4391*	Multiple Teaching Practices *EDUC 4333*	Student Teaching with Seminar *SCIE 4607 & 4107*
Freshman Pathway Spring start 7 semesters		STEP 1	STEP 2 Knowing and Learning	Classroom Interactions	Perspectives on Science and Math	Research Methods	Multiple Teaching Practices	Student Teaching with Seminar
Sophomore Pathway Fall start 6 semesters			STEP 1	STEP 2 Knowing and Learning	Classroom Interactions	Perspectives on Science and Math	Research Methods Multiple Teaching Practices	Student Teaching with Seminar
Sophomore Pathway Spring start 5 semesters				STEP 1	STEP 2 Knowing and Learning	Classroom Interactions Perspectives on Science and Math	Research Methods Multiple Teaching Practices	Student Teaching with Seminar
Junior/Senior Pathway Fall start 4 semesters					STEP 1 Knowing and Learning	STEP 2 Classroom Interactions	Perspectives on Science and Math Research Methods Multiple Teaching Practices	Student Teaching with Seminar
Post-Baccalaureate Pathway Spring start 3 semesters						STEP 1 & 2* Knowing and Learning Perspectives on Science and Math	Classroom Interactions Research Methods Multiple Teaching Practices	Student Teaching with Seminar

*Combined course restricted to seniors and post-bacs

Mathematics
Students seeking Mathematics certification will also take MATH 2330, Functions and Modeling. This course may be taken the spring semester of either the sophomore or junior year and must be completed prior to Student Teaching.

Figure 2: UTeach Arlington entry points

RESULTS

While students supported by Noyce Scholarships have finished their preparation programs, no UTeach Arlington student has graduated yet. The 2013-2014 academic year is the last year of our new course rollout. UTeach Arlington students will have their first opportunities to enter into Student Teaching in January and August of 2014. The first impacts of the Noyce Scholarships are evident in Table 2. Whereas typically one high school science teacher was prepared per year at UT Arlington, and zero physics teachers, awarding Noyce Scholarships moved the total up to five or six science teachers per year, including the first physics teacher produced in a number of years. The effectiveness of our UTeach replication can be seen in our secondary science and math teacher pipeline data (Table 4). There are approximately 60 students on track to enter into secondary science and mathematics student teaching in 2014.

Table 4: Secondary science and math teacher pipeline at UT Arlington

Major	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012	Spring 2013
Physics	2	3	4	12	12	11
Biology	48	36	71	59	79	54
Chemistry	7	5	15	10	12	5
Geology	2	1	1	3	9	8
Math	12	15	33	33	69	59
Other	18	34	30	30	26	25
Total	71	60	124	117	182	137

CONCLUSIONS

The introduction of NSF Robert Noyce Teacher Scholarships on the UT Arlington campus did drive an increase in the production of science teachers. While that increase looks impressive on a percentage basis, it moved UT Arlington only into the mid-single digits of science teacher production, and physics teacher production was still rare. While this improvement was welcome, it was much more modest than our goals. Our Noyce Scholarship intervention would have likely produced a larger increase if the authors were not also actively working on the UTeach replication project. Once the UTeach replication was begun, the Noyce Scholarship program became a more complementary project than a stand-alone effort.

The combined approach of a UTeach replication supplemented with a Noyce Scholarship program is poised to produce dramatic results at UT Arlington. Our first class of UTeach Arlington trained secondary math and science teachers will enter student teaching the spring and fall of 2014. It is anticipated that there will be more than 50 student teachers. Approximately half will be science teachers and half math teachers, and there will be multiple physics majors in the group. While the authors do not feel that we will be producing enough physics (or chemistry) teachers yet, this is a very promising start.

ACKNOWLEDGEMENT

This work was supported by Texas Instruments, AT&T, the Michael and Susan Dell Foundation, the Texas Education Agency, the Sid Richardson Foundation, the George and Fay Young Foundation, and the U.S. National Science Foundation grant #0833343 under the Robert Noyce Scholarship Program for Teachers of Science and Mathematics.

REFERENCES

Ingersoll, R. (2003). *Is there really a teacher shortage? A research report co-sponsored by The Consortium for Policy Research in Education and The Center for the Study of Teaching and Policy.*

National Science Foundation web site. (n.d.). Available at http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5733

Rankin, M. A. (2006). *UTeach Natural Sciences overview presentation.* 29 November 2006, Fort Worth, TX.

The University of Texas at Austin. (n.d.). *UTeach Natural Sciences web site.* Available at https://uteach.utexas.edu/About/Program%20History

The University of Texas at Austin. (n.d.). *UTeach Natural Sciences web site.* Available at http://uteach-institute.org/publications

GREGORY R. HALE
RAMON E. LOPEZ
ANN M.L. CAVALLO
ERIN E. GONZALES
UTeach Arlington, The University of Texas at Arlington, Arlington, TX, USA

sciED

Scientia in educatione 8(Special Issue), 2017
p. 207–213
ISSN 1804-7106

Inquiry Based Science Education and Getting Immediate Students' Feedback about Their Motivation

Martina Kekule, Vojtech Zak, Zuzana Jeskova,
Katarina Kimakova, Maria Ganajova, Marian Kires

Abstract

The paper is based on collecting evidence of the Establish project impact on students. For the purpose two questionnaires based on the existing tools have been used. Questionnaire 1 is a part of Intrinsic Motivation Inventory (IMI) based on the Self-determination theory. It is aimed at assessing students' interests, their perceived choice and usefulness of implemented learning units and should be answered after each learning unit/several IBSE activities. Several items of CLES questionnaire are included there as well. Questionnaire 2 assesses the impact on students' attitudes towards science and technology and on their knowledge about nature of building up science knowledge. Both questionnaires exist in the lower and upper secondary school versions. The paper presents selected data and results which were obtained by addressing the Questionnaire 1, so that the focus is on getting students' feedback about their intrinsic motivation. Our assumption is that active learning is associated with positive intrinsic motivation of students. That is why we find as very important that educators have a possibility to understand the phenomenon more deeply. We aim to present the reliable tool for getting the feedback and to present a way of data processing which does not need advanced statistical methods, so that teachers (as well as science education researchers) can use and analyze data obtained by the tool. Means and standard deviations for items of the subscales Interest/Enjoyment, Perceived choice and Value/Usefulness were computed. To determine the consistency of results, the Standard Pearson correlation coefficient was computed for all items within the subscales. Based on the findings, we can conclude that participants' answers (questionnaire results) were consistent (not responded mechanically).

Key words: students' feedback, motivation, questionnaire, IBSE.

INTRODUCTION

The paper is focused on getting students' feedback about their motivation just after their science lessons led by inquiry teaching method. The presented fast feedback tool has been used during the ESTABLISH project (n.d.). The objective of the project (funding from the European Community's Seventh Programme [FP7/2007–2013] under grant agreement no. 244 749) is the wide use and dissemination of inquiry-based teaching method for science education (IBSE) at secondary schools across Europe. Over the course of the project, a number of ESTABLISH teaching and learning materials (units) have been developed and adapted for the use in classrooms in participating countries. The rationale for ESTABLISH lies in creating authentic learning environments for science by bringing together and involving all relevant stakeholders, particularly the scientific and industrial community, policy makers, parents, science education researchers and teachers to drive change in the classroom.

For collecting evidence of the impact of the Establish project on students two questionnaires based on the existing tools have been used. Questionnaire 1 is a part of Intrinsic Motivation Inventory (IMI) (n.d.) based on the Self-determination theory developed by Ryan and Deci (2000). It is aimed at assessing students' interests, their perceived choice and usefulness of implemented learning units and should be answered after each learning unit/several IBSE activities. Several items of CLES questionnaire (Fraser, Taylor & White, 1994) are included there as well. Questionnaire 2 assesses the impact on students' attitudes towards science and technology and on their knowledge about nature of building up science knowledge. Both questionnaires exist in the lower and upper secondary school versions (12–15/16–19 year-old students).

The paper presents chosen data and results which were obtained by addressing the Questionnaire 1 (when assigning to students from Slovakia), so that the focus is on getting students' feedback about their intrinsic motivation. Our assumption is that active learning is associated with positive intrinsic motivation of students. That is why we find as very important that educators have a possibility to understand the phenomenon more deeply. We aim to present the reliable tool for getting the feedback and to present a way of data processing which does not need advanced statistical methods, so that teachers (as well as science education researchers) can use and analyze data obtained by the tool.

MORE ABOUT THE QUESTIONNAIRES

As it is stated in the introductory part, the questionnaire focused on getting immediate feedback includes prevalently parts of Intrinsic Motivation Inventory (IMI). The inventory consists altogether of 45 items which belong to 7 subscales (dimensions). The statistical characteristics of the inventory allow to a researcher to create her/his own questionnaire where she/he includes just items belonging to the dimensions which she/he is interested in. Mainly because of the time limit (we needed a tool for the fast feedback), we chose for our tool just items concerning three dimensions: interest/enjoyment, value/usefulness and perceived choice. "The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation, the other two dimensions are theorized to be positive predictors" (Intrinsic Motivation Inventory, n.d.).

The dimension Interest/Enjoyment measures to what extent students like the performed activity and find it interesting. The dimension Perceived Choice measures to what extent students perceive their choice when performing a given activity. The dimension Value/Usefulness measures how students perceive the value/usefulness of a given activity for themselves. The form of an item is a statement which students assess as a true or not true. For the assessment they use 7 point scale:

1 – 2 – 3 – 4 – 5 – 6 – 7

not at all true – … – somewhat true – … – very true

Some items express very similar content what was perceived by some students as annoying. However, it is necessary when we need to judge if students really assessed the statement or if they only put marks by chance. This consistency in students' responses will be discussed later.

The second part of the questionnaire is based on the CLES questionnaire — the Constructivist Learning Environment Survey. In the section we are focused on ways of students' communication during the activities as an aspect of social interaction that can influence motivation in general as well. The questionnaire origins from the constructivist theory and is widely used for evaluating lessons from this perspective. We used a part of the questionnaire which contains 6 items focusing on students' communication during the activity (e.g. passivity or activity in the initiation of communication). Students assess how often they communicate using 5 point scale.

Description of the tool

Our questionnaire is intended to be used as a fast feedback after the learning unit and it will be assigned immediately after the unit (at the end of the lesson). It takes about 10 minutes to complete this questionnaire. The questionnaire exists in a version for lower (marked B, about 12 to 15 year-old, ISCED 2), and upper (marked A, about 16 to 19 year-old, ISCED 3) secondary schools.

Questionnaire A — for upper secondary schools

It contains 25 items with the 7 point scale adopted from the IMI and it focuses on assessing the three discussed dimensions (subscales).

Interest/Enjoyment subscale shows the extent to which students like the performed activity and find it interesting. This subscale comprises a total of 8 items, namely 3, 5, 7, 11, 12-R, 15, 17, and 23. The "R" with item no. 12 means that a reverse score is needed. It is an item with the opposite meaning to the other items. It is possible to gain 56 points in total.

Perceived Choice subscale shows how students perceive their choice when performing a given activity. This subscale comprises a total of 8 items, namely 2, 8-R, 9, 14-R, 18-R, 20-R, 22, and 24-R. The "R" means again that a reverse score is needed and it is possible to gain 56 points in total as well.

Value/Usefulness subscale shows how students perceive the value/usefulness of a given activity for themselves. This subscale comprises a total of 9 items, namely 1, 4, 6, 10, 13, 16, 19, 21, and 25. It is possible to gain 63 points in total.

The second part of the questionnaire was taken from the CLES. It contains 6 items and it is possible to gain 30 points in total.

As an example, we present below which items the subscale Interest/Enjoyment consists of:

- While I was doing activities in the learning unit, I was thinking about how much I enjoyed it. (3)
- Activities in the learning unit were fun to do. (5)
- I enjoyed doing activities in the learning unit very much. (7)
- I felt like I was enjoying activities while I was doing them. (11)
- I thought these were very boring activities. (12-R)
- I thought this was a very interesting learning unit. (15)
- I would describe activities in the learning unit as very enjoyable. (17)
- I would describe activities in the learning unit as very fun. (23)

We can see that all eight items express the same (or a very similar) thing: the extent to which students like the performed activity (or the learning unit) and find it interesting, in other words whether the learning unit (activities included in it) was interesting/enjoyable/not boring. The item no. 12-R is reverse ("negative").

QUESTIONNAIRE B — FOR LOWER SECONDARY SCHOOLS

This version contains 17 items with the 7 point scale adopted from the IMI and it focuses on assessing the two following dimensions: Interest/Enjoyment and Value/Usefulness.

Interest/Enjoyment subscale shows the extent to which students like the performed activity and find it interesting. This subscale comprises a total of 8 items, namely 2, 4, 6, 8, 9-R, 11, 13, and 16. The "R" with item no. 9 means that a reverse score is needed. It is possible to gain 56 points in total.

Value/Usefulness subscale shows how students perceive the value/usefulness of a given activity for themselves. This subscale comprises a total of 9 items, namely 1, 4, 6, 10, 13, 16, 19, 21, and 25. It is possible to gain 63 points in total.

The second part of the questionnaire was taken from the CLES. It contains 6 items and it is possible to gain 30 points in total.

The above mentioned research tools are available on the web page (Kekule & Žák, n.d.).

AN EXAMPLE OF DATA PROCESSING

BASIC INFORMATION — MEANS OF SELECTED ITEMS

As an example of basic data processing, we present a part of the Slovak study which includes approx. 1 500 students. We are focusing on the dimension Interest/Enjoyment (Questionnaire A, upper secondary schools). As mentioned above, it includes 8 items, namely 3, 5, 7, 11, 12-R, 15, 17, and 23. Means (and standard deviations) were computed using software Statistica (see Table 1 and Figure 1), however, e.g. Microsoft Excel can be recommended as well.

The scale has a range from 1 to 7, thus, the average is 4. We can see from the table and the graph that direct items (no. 3, 5, 7, 11, 15, 17, and 23) are assessed positively (nearly 5 on the scale) whereas the only reverse item (no. 12)

Table 1: Means and standard deviations for items of Interest/Enjoyment dimension

	Descriptive Statistics (Date Slovakia_1A.sta)	
Variable	Mean	Std. Dev.
Part1_3	4.75	1.55
Part1_5	4.99	1.57
Part1_7	4.90	1.55
Part1_11	4.82	1.53
Part1_12R	2.79	1.67
Part1_15	4.96	1.46
Part1_17	4.89	1.54
Part1_23	4.80	1.56

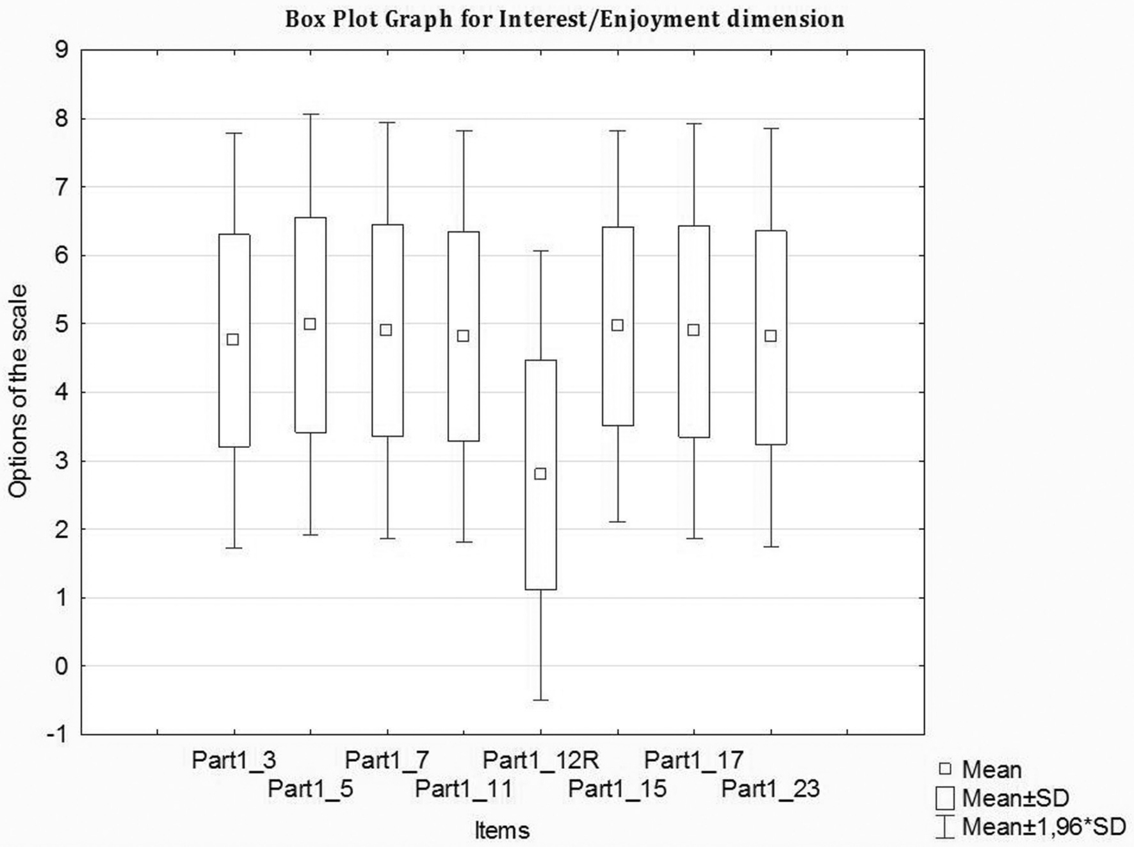


Figure 1: Box Plot Graph for Interest/Enjoyment dimension

negatively (approx. 3 on the scale). We can conclude that students assessed the learning unit (activities included in it) as rather interesting/enjoyable. We can also notice that students were consistent in their evaluation because they assessed direct items positively and the reverse item negatively. The opinion expressed by students can be considered as reliable (more details below).

MORE DETAILED INFORMATION — CONSISTENCY OF RESULTS

Based on the fact that each of three dimensions (subscales) mentioned above consists of several similar items (and reverse items as well), we can explore whether students really assess the statement or if they only put marks by chance. In other words, we can explore whether students respond the items seriously (consistently) or not.

Table 2: Standard Pearson correlation coefficient for Interest/Enjoyment dimension

	Correlations (Date Slovakia_1A.sta) Marked correlations are significant at $p < 0.050\,00$ $N = 1\,469$ (Casewise deletion of missing data)							
Variable	Part1_3	Part1_5	Part1_7	Part1_11	Part1_12R	Part1_15	Part1_17	Part1_23
Part1_3	1.000 000	0.763 765	0.762 522	0.782 930	−0.524 958	0.716 731	0.733 328	0.688 135
Part1_5	0.763 765	1.000 000	0.816 786	0.807 440	−0.558 890	0.745 488	0.756 493	0.756 527
Part1_7	0.762 522	0.816 786	1.000 000	0.807 380	−0.545 114	0.768 743	0.778 445	0.764 461
Part1_11	0.782 930	0.807 440	0.807 380	1.000 000	−0.589 269	0.762 909	0.789 213	0.760 800
Part1_12R	−0.524 958	−0.558 890	−0.545 114	−0.589 269	1.000 000	−0.567 658	−0.534 214	−0.518 259
Part1_15	0.716 731	0.745 488	0.768 743	0.762 909	−0.567 658	1.000 000	0.785 376	0.760 059
Part1_17	0.733 328	0.756 493	0.778 445	0.789 213	−0.534 214	0.785 376	1.000 000	0.792 286
Part1_23	0.688 135	0.756 527	0.764 461	0.760 800	−0.518 259	0.760 059	0.792 286	1.000 000

To determine this characteristic — consistency of results — Standard Pearson correlation coefficient was computed (using software Statistica, see Table 2; Microsoft Excel enables users to compute correlation coefficients as well).

We can see from the table that values of the correlation coefficient are from 0.69 to 0.82 between direct items and from −0.52 to −0.59 between the reverse and direct items. All correlations are statistically significant at $p < 0.05$. Thus in both cases, we can speak about a high correlation. Based on this findings, we can conclude that students' answers (questionnaire results) are consistent. They express students' opinion repeatedly in the same (or a very similar) way, so we can assume that it is meant seriously.

CONCLUSIONS

Our assumption is that active learning is associated with positive intrinsic motivation of students. That is why we have presented the tool for getting students' feedback after learning lessons. The investigated lessons were taught by inquiry based teaching method (IBSE) according to learning units created within the ESTABLISH project. The assessment tools are available in English version on the web page (Kekule & Žák, n.d.) for both teachers and researches. Their administration takes about 10 minutes, so that it is appropriate in relation to the time of the typical learning unit.

The above presented example of results was obtained by using software Statistica. We recommend this program, especially for research purposes, however, other common statistical programs can be used for gaining results intended for teaching and learning purposes as well, e.g. MS Excel. In other words, the data processing does not need advanced statistical methods, so that teachers (as well as science education researchers) can analyse data obtained using the tool by themselves.

Besides the common basic statistics (mainly means and standard deviations), the way how to determine consistency of results was presented. In case of the high correlation between items related to the same dimension, we can speak about the high consistency of findings. Thus, we can conclude that students' opinions are meant seriously. The presented tool enables teachers and researchers to gather and distinguish reliable data. In this case, the tool can be considered as a reliable tool.

REFERENCES

Deci, E. L. & Ryan, R. M. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*, 68–78. Available at http://www.selfdeterminationtheory.org/questionnaires/10-questionnaires/50

ESTABLISH project. (n.d.). Available at http://www.establish-fp7.eu

Fraser, B. J., Taylor, P. C. & White, L. R. (1994). *CLES: An instrument for monitoring the development of constructivist learning environments.* Paper presented at the annual meeting of the American Educational Research Association, New Orleans.

Intrinsic Motivation Inventory (IMI). (n.d.). Available at http://www.selfdeterminationtheory.org/questionnaires/10-questionnaires/50

Kekule, M. & Žák, V. (n.d.). *Research tools, tools for the Establish project.* Available at http://kdf.mff.cuni.cz/vyzkum/tools.php

---

MARTINA KEKULE
VOJTECH ZAK
Faculty of Math. and Physics, Charles University, Prague, Czech Republic

ZUZANA JESKOVA
KATARINA KIMAKOVA
MARIA GANAJOVA
MARIAN KIRES
Faculty of Science, Pavol Jozef Safarik University, Kosice, Slovak Republic

sciED
Scientia in educatione 8(Special Issue), 2017
p. 214–222
ISSN 1804-7106

Exergy in School?

Tomaž Kranjc, Nada Razpet

Abstract

Students at all levels of physics instruction have difficulties dealing with energy, work and heat in general and, in particular, with the concepts of efficiency and ideal heat engine, and the maximum performance of refrigerators and heat pumps (Cochran & Heron, 2006; Bucher, 1986). The reason for the difficulties is an insufficient understanding of the second law of thermodynamics (Kesidou & Duit, 1992). In order to make these topics less difficult, the concept of exergy — well established as a powerful analytical tool in technical thermodynamics — describing the "quality" of energy, seems in our judgment to be worthy of inclusion in the physics curriculum at all levels. Its introduction does not add another law. It facilitates the understanding of irreversibilities (as the destruction of exergy) and gives a deeper meaning to the second law. In the treatment of heat engines the second-law efficiency throws a new light on the notions of an ideal and a real engine (similarly for a refrigerator or a heat pump). Exergy introduces, in a natural way, a distinction between various forms of energy according to its quality — availability for performing work. "Energy reserves", which can be better understood with the help of exergy, are of practical interest. From the thermodynamic point of view, a more correct term would be "availability reserves"; all around us, there are huge quantities of energy (in atmosphere, in oceans etc), but of very limited availability, i.e., of limited exergy.

In order to identify common misconceptions and difficulties encountered by students in the learning of the first and second law of thermodynamics, particularly in connection with heat engines and similar cyclic devices, we conducted a combined research among students of the Primary School Education at the Faculty of Education (UPR PeF) and of Biodiversity, Bioinformatics and Mediterranean Agriculture at the Faculty of Mathematics, Natural Sciences and Information Technologies (UPR FAMNIT) of the University of Primorska. Based on interviews and questionnaires given to two groups of students — an experimental and a control group — in the beginning and the end of the semester, we investigated the influence (and possible advantages) of the introduction of the concept of exergy and the second-law efficiency.

In the presentation, we show a few examples that were treated with the experimental group in order to motivate the students and to make them familiar with the concept of exergy: the "energy losses" of a car engine and an analysis of improvements still allowed by nature; exergy loss associated with heat conduction; a simple exergy analysis of a heating house system (considering energy and exergy fluxes). We list some of the problems encountered by the students and the most common misconceptions as could be identified from the tests, questionnaires and interviews. An additional goal of the investigation is to test a longer-term knowledge of students.

From our research it would appear that exergy and the second-law efficiency are useful concepts which make it possible for students to get a better grasp of the material and to not only obtain a clearer understanding and knowledge of standard topics like heat engines, but also a broader view and insight into the meaning of energy and both the first and the second law, and their interrelation.

Key words: heat, exergy, second-law efficiency.

INTRODUCTION

In physics instruction, the chapter on heat is considered difficult and abstract, despite its usefulness and broad applications in technology. For the understanding of the laws of thermodynamics one needs to know and understand the concepts of work, heat, energy, and entropy, and develop an intuitive feeling for them. Heat engines and similar cyclic devices (refrigerators, heat pumps, gas turbines, fuel cells, rocket engines, etc.) are important examples of technology based on thermodynamics and, in fact, one of the goals of teaching thermodynamics is "an appreciation of the limits to efficiency" (Baierlein, 1994). The school physics instruction is usually limited to heat engines, refrigerators, and heat pumps (Arnaud, Chusseau & Philippe, 2010; Bartlett, 1976; Leff & Teeters, 1977; Tobin, 1969). Their efficiency (or a suitable measure of their performance) is introduced and calculated and a comparison is made to the efficiency of ideal (Carnot) engines. For engines using (the ideal) gas as their working substance the efficiency can be determined by a direct calculation of cyclic changes. But it is more important for students to understand the limits of the functioning of heat devices as imposed by the laws of thermodynamics.

In physics instruction at the high school level or in university programs that include an introductory course of physics for non-physics majors (e.g. chemistry, biology, mathematics, etc. majors) one again and again sees that students have not learned certain simple facts and/or have not understood them. In order to achieve better results numerous methods were developed and applied (Baierlein, 1994; Tobin, 1969; Cochran & Heron, 2006; Das, 1994; Finfgeld & Machlup, 1960; Leff & Teeters, 1977; Marcella, 1992; Reif, 1999; Reynolds, 1994; Samiullah, 2007; Kesidou & Duit, 1992). They were supposed to help gain a better understanding and a higher level of competency in applying the laws and methods of thermodynamics.

In view of a small success of these methods and efforts, we join proposals aiming at introducing the concept of exergy into the instruction of thermodynamics (from the elementary school level on) (see Viglietta, 1990), together with related notions and quantities. We believe that, based on the concept of exergy and the second-law efficiency, students can better understand and memorize the functioning and the underlying principles of heat devices and, at the same time, largely extend their understanding of some relevant topics of the present days. Besides, a study of a much broader spectrum of devices, device parts, and processes is made possible.

HEAT ENGINES AND STUDENT UNDERSTANDING

Among the main instructional tools illustrating cyclic changes repeated by heat engines and similar devices are diagrams of heat flows and work. Schematic presentations of heat flows and work (as in Figure 1) are easy to read but students often do not see connections to real engines — they do not know where the system (heat engine, refrigerator, heat pump) is "hidden" or where in the real device are the heat reservoirs.

An additional problem occurring with this kind of presentation of a heat device is the fact that it is not obvious from it how the supplied heat divides between the produced work and exiting heat. This is not determined by the energy but by the entropy law which has to be additionally built into the diagram.

Cochran and Heron (2006) assessed the knowledge and understanding of the second law among different groups of students and presented the responses to questions that they posed based on heat flow and work diagrams (Figure 1). Students received three different diagrams (for a heat-engine, refrigerator and a "strange device", Figure 1); for each of them they had to tell if such a device could function and explain why they thought so. The results obtained at final exams gave only about 30 % correct answers.

Testing second year students of the Primary school Education at the Faculty of Education (UPR PeF) and Biodiversity, Bioinformatics and Mediterranean Agriculture at the Faculty of Mathematics, Natural Sciences and Information Technologies (UPR FAMNIT) of the University of Primorska (in the academic year 2011/2012) we obtained similar results as in (Cochran & Heron, 2006) (between 30 % and 40 % correct answers).

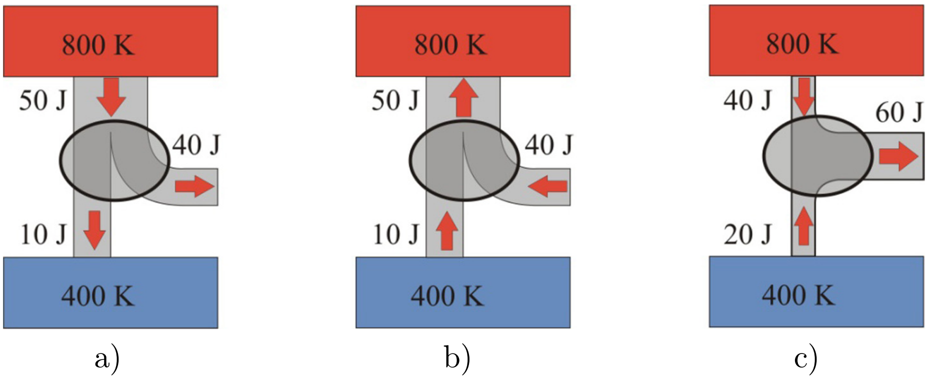


Figure 1: Heat devices for test questions (Ref. (Cochran & Heron, 2006)). a) A proposed heat engine, b) a proposed refrigerator, c) a "strange device". Students had to determine if the devices could function and why. (Figure 1 in Ref. (Cochran & Heron, 2006))

Three additional questions were about the "ideal" heat engine for which it was repeatedly emphasized in class to be a synonym for the Carnot heat engine. The first question asked for the efficiency of an ideal heat engine, the second, what would be the efficiency of an imaginary ideal heat engine operating between the extreme temperatures of 300 K and 299 K (the example was solved in the class), for the third question students had to draw the heat and work flow diagram of an ideal engine.

The portions of correct answers were as follows. The first question: 35 %, the second question: 44 %, the third question: 21 %, the total number of students: 34. 53 percent (18 students) gave 100 % as the answer to the first question (i.e. they wrote that the efficiency of the ideal heat engine is 100 %). It is interesting that none of the students who claimed the efficiency of an ideal heat engine to be 100 % drew as the answer to question 3 the diagram on the right of Figure 2, which would be a logically consistent answer. 62 % drew approximately the diagram in Figure 2 left (with the line showing the flow of emitted Q_L being more or less thin), obviously suggesting that the ideal heat engine directs "almost all" the received heat into work.

It is obvious that students are not really able to use the second law when they think about cyclic heat devices. Bucher (1986) proposed and other authors (Wallingford, 1989; Yan & Chen, 1990, 1992; Bucher, 1993; 2007; Wallingford, 1989; Yan & Chen, 1990, 1992) subsequently further developed a new type of diagrams (Bucher diagrams), which include both the first and the second law of thermodynamics. However, the new diagrams do not seem to have enough appeal, visualizing force and simplicity to be adopted in school curriculum.

In presenting any study material, the choice of basic concepts is of upmost importance. In the treatment of thermodynamic systems such a new quantity could be

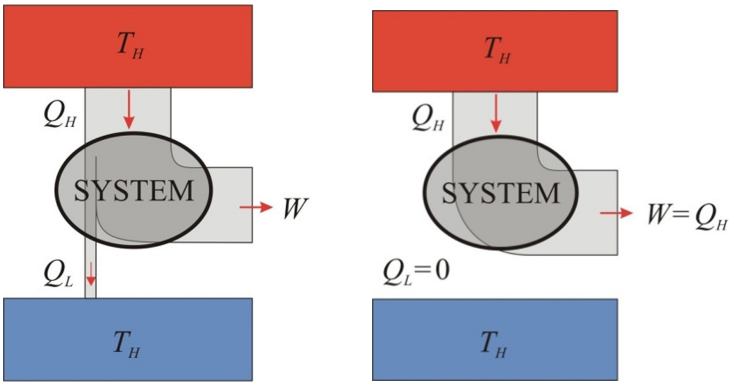


Figure 2: Left: Flow of heat and work in an ideal heat engine as shown by a majority of students. Right: None of the students who answered that the efficiency of the ideal heat engine is 100 % drew a diagram with $Q_L = 0$, which would correspond to 100 % efficiency

exergy (Rant, 1956). Not only it allows a more reliable analysis of heat engines and similar devices, but also offers a better insight into the role of energy of arbitrary processes and into the very understanding of energy and its uses. It could be characterized as a concept for the *valuation of the quality of energy.* We believe it to be a useful, effective and at the same time a sufficiently simple concept and therefore appropriate to be introduced in a sensible way into the school physics curriculum.

EXERGY AND THE SECOND LAW-EFFICIENCY

Energy has two facets, *quantity* and *quality.* The first law of thermodynamics states that energy is preserved, i.e., that it "cannot be destroyed or come out of nothing". Energy appears in many different forms, like kinetic, potential, elastic, electric, chemical, atomic, thermal, etc., and it can change from one form into another. Regardless of the processes and transformations the amount of energy stays the same.

Since energy is preserved we really should not be talking about "energy losses". However, energy that is preserved in its amount and is therefore not lost does not have "the same value" in every form. In all real processes its *"quality"* decreases. For example, possibilities of using the (potential) energy of a weight hanging above the ground are greater than possibilities for using its internal energy coming from the change of the potential energy when the weight falls on the ground and warms up a little bit.

Let us call *exergy* the quantity which expresses the quality of energy. We can say that exergy (E^k) is the energy that can be, in given circumstances, transformed into an arbitrary other form of energy. We often say that exergy is the part of energy that can be used for work in its entirety or, represents the available work. Exergy is therefore the "useful" part of energy. The remaining — useless part — is called *anergy* (E^a). The entire energy (E) can be written as $E = E^k + E^a$.

Different forms of energy can then be divided into three classes, depending on the "quality":

- Energy that can be completely used for work = exergy
- Energy that can be partly used for work = exergy + anergy
- Energy that cannot be transformed into work = anergy

Mechanical, electric and (approximately) chemical energy can transform into work in its entirety (if we ignore irreversibilities which are part of any real process and are a consequence of different dissipation processes like friction). In the case of an electric engine the electric work can be (almost) completely transformed into the mechanical work. The thermal energy can be (partly) transformed into work in the case where the system is not (yet) in equilibrium with its environment.

What is the exergy of a certain amount of heat (Q_H) that can be taken from a heat reservoir at temperature T_H? A Carnot heat engine is the most efficient device for converting heat into work. The exergy of heat Q_H is the portion which is available for work and this is $|W| = Q_H(1-T_0/T_H)$ (T_0 being the lower reservoir temperature). The partition of Q_H into exergy and anergy is therefore $Q_H = |W| + Q_H(T_0/T_H)$.

This result shows that exergy is not an "absolute" quantity depending only on the quantity of invested energy but is also dependent on circumstances: it depends on the temperatures at which a Carnot heat engine absorbs and emits heat. The efficiency $\eta_C = 1 - T_L/T_H$ is greater if the temperature at which the Carnot engine emits heat is lower. This is often (though not always) the temperature of the environment T_0 ($T_L = T_0$).

Efficiency tells us what limitations for converting heat into work are imposed by nature under given circumstances (T_0 and T_H, say). For given T_0 and T_H the work ($|W_{\text{max}}|$) that can be obtained from heat Q in the best case scenario (reversibility of the process) equals $|W_{\text{max}}| = \eta_C Q$. In the hypothetical example where $T_0 = 299$ K and $T_H = 300$ K, η_C would equal 1/300 or about 0.3 %. Even though this is not much it is the most allowed by nature in given circumstances. Therefore this is the "ideal" efficiency of an "ideal" heat engine.

Due to unavoidable irreversibility of real processes and also for other reasons the work ($|W_{\text{real}}|$) is actually smaller than the maximum ($|W_{\text{max}}|$) and the same holds true for the actual efficiency (η), $\eta < \eta_C$. Therefore, it seems reasonable to compare the actual efficiency of a device with the maximum possible efficiency. To do that we introduce the *second-law efficiency of a heat engine* (ν) (Backhaus & Schlichting, 1984) as $\nu = \eta/\eta_C$. In the "ideal" case, $\nu = 1$.

The information about the second-law efficiency of a heat engine is important because it tells us what the "reserves" are when one gets work out of heat. If $\nu = 1$, there is no room left for any improvement, even though the efficiency η might be small. If, however, $\nu < 1$, nature still allows improvements in the engine's efficiency.

Let us formulate the Second Law of Thermodynamics in terms of exergy instead of entropy:

- Exergy is preserved under all reversible changes.
- In irreversible transformations exergy decreases ("exergy losses") and changes into anergy.

INTRODUCING EXERGY INTO THE TEACHING OF THERMODYNAMICS

In school year 2012/2013 we again tested second-year students of the Primary school Education at the UPR PeF) and Biodiversity, Bioinformatics and Mediterranean Agriculture at the UPR FAMNIT.

Students were divided into two groups. With one of them we used the standard approach to cover the chapter on heat engines, refrigerators, and heat pumps (without introducing exergy). With the other one we introduced exergy and, besides the standard thermal efficiency for heat engines ($\eta = |W|/Q_H$) or coefficient of performance (COP) for refrigerators ($Q_L/|W|$) and heat pumps ($Q_H/|W|$) we also introduced the second-law efficiency, $\nu = \eta/\eta_C$. The second group, according to our observations, obtained a better insight into the understanding of energy, its consumption and uses, and with that of energy issues in general (which implicitly includes the issues concerning ecology). In testing, however, we were interested how the students from the second group were able to answer questions which belong to the standard coverage of thermodynamics.

The whole group had 43 students who were divided into two groups, the first one (for the standard approach) had 21 students, the second (for the introduction of exergy) had 22 students. The obtained results (Figure 3) show a convincingly better answers of the second group to the first three questions. It appears that through the treatment of heat devices with the help of exergy they obtained a better insight and feeling for the content of especially the second law of thermodynamics.

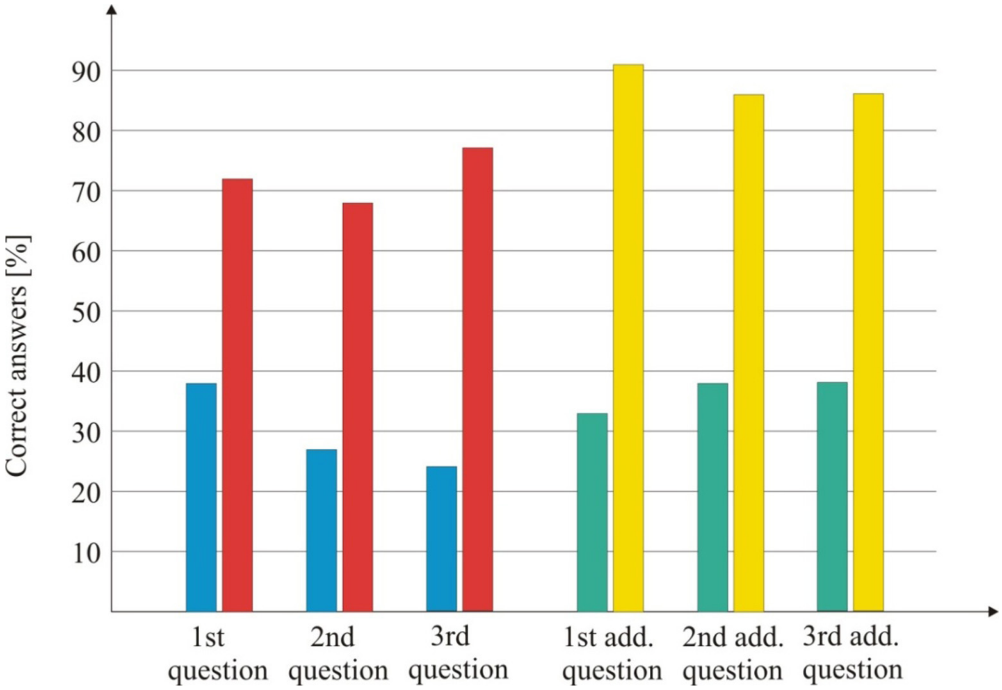


Figure 3: The correct answers to questions from Fig. 1 and to the three additional questions. The first column of each question refers to the first group, the second to the second group

Also with the three additional questions about the "ideal" heat engine (cf. the text after Figure 1) the second group did much better. The results are shown in Figure 3. The example from the second question was not solved in class this time, and in question 3 they had to add an explanation of the diagram that they drew.

CONCLUSIONS

Thermodynamics is both an abstract (and for this reason difficult) and a technologically important chapter of physics. It is therefore worth making an effort to acquaint students with some basic concepts and ideas and also with the simplest information about technical applications. Among these the most important in school are cyclic heat devices (heat engines, refrigerators, heat pumps).

Even though it is difficult to introduce innovations in the time when the scope of physics instruction is diminishing at all levels, we believe that after several decades (Rant, 1956) or even more of a successful introduction especially in the field of technical thermodynamics it is reasonable to think about introducing the concept of exergy into the physics curriculum at all levels.

It appears that with the help of exergy it is possible to better understand the First and the Second Law of Thermodynamics and the limitations of transforming heat into work set by nature. At the same time one can better understand where it is possible to further improve one's devices (where nature still allows it) and what is true the meaning of exploitation of energy and energy reserves.

After instruction of thermodynamics based on the concept of exergy, students have

- showed a better understanding of the significance of the two laws of thermodynamics,
- got to know and appreciate the concept of the *quality* of energy,
- acquired a better insight into the restraints put by the second law on natural processes,
- arrived at a better understanding of reversible and irreversible processes in terms of exergy losses,
- got to understand much better cyclic devices (heat engines, refrigerators, heat pumps),
- got to understand the meaning of "ideal" devices in terms of the 1st law efficiency and the 2nd law efficiency,
- were able to do simple energy-exergy analyses,
- arrived to understand better terms like "energy reserves", "energy crisis", "energy degradation", "waste of energy", "lost work", "renewable energy sources", "availability" etc., and to build a better attitude toward ecological issues connected to energy needs.

With the use of exergy it was demonstrated at least on the experimental groups of students that the exergy concept helped them to a better understanding of the material which already is a part of the existing school curriculum and has to be mastered by students.

It is our opinion that the introduction of the concept of exergy leads to a better and deeper students' understanding and insight of the fundamental laws of thermodynamics as well as of their use in many technical and social applications. At the same time, it does not require changes of the curriculum (but the introduction of a new concept), it requires no extra time and no increase in the study input. Therefore we expect a serious discussion and consideration about a suitable introduction of exergy into the classroom instruction.

REFERENCES

Arnaud, J., Chusseau, L. & Philippe, F. (2010). A simple model for Carnot heat engines. *Am. J. Phys.*, 78(1), 106–110.

Backhaus, U. & Schlichting, H. J. (1984). Der exergetische Wirkungsgrad. *Der Physikunterricht*, 18(3), 58–61.

Baierlein, R. (1994). Entropy and the second law: A pedagogical alternative. *Am. J. Phys.*, 62(1), 15–26.

Bartlett, A. A. (1976). Introductory experiment to determine the thermodynamic efficiency of a household refrigerator. *Am. J. Phys.*, 44(6), 555–559.

Bucher, M. (1986). New diagram for heat flows and work in a Carnot cycle. *Am. J. Phys.*, 54(9), 850–851.

Bucher, M. (1993). Diagram of the second law of thermodynamics. *Am. J. Phys.* 61(5), 462–466.

Bucher, M. (2007). Comment on "Development and assessment of research-based tutorials on heat engines and the second law of thermodynamics", by Matthew, J. Cochran, Paula, R. L. Heron. *Am. J. Phys.*, 75(4), 377–379.

Cochran, M. J., & Heron, P. R. L. (2006). Development and assessment of research-based tutorials on heat engines and the second law of thermodynamics. *Am. J. Phys.*, 74(8), 734–741.

Das, S. K. (1994). Comment on "Entropy production and the second law of thermodynamics: An introduction to second law analysis", by Thomas V. Marcella. *Am. J. Phys.*, 62(12), 1151–1152.

Finfgeld, C. & Machlup, S. (1960). Well-Informed Heat Engine: Efficiency and Maximum Power. *Am. J. Phys.*, 28(4), 324–326.

Kesidou, S. & Duit, R. (1992). Students' conceptions of the second law of thermodynamics: An interpretative study. *J. Res. Sci. Teach.*, 30, 85–106.

Leff, H. S. & Teeters, W. D. (1977). EER, COP, and the second law efficiency for air conditioners. *Am. J. Phys.*, 46(1), 19–22.

Marcella, T. V. (1992). Entropy production and the second law of thermodynamics: An introduction to second law analysis. *Am. J. Phys.*, 60(10), 888–895.

Rant, Z. (1956). Exergie, ein neues Wort für 'Technische Arbeitsfähigkeit'. *Forsch. Ing. Wes.*, 22, 36–37.

Reif, F. (1999). Thermal physics in the introductory course: Why and how to teach it from a unified atomic perspective. *Am. J. Phys.*, 67, 1051–1062.

Reynolds, R. E. (1994). Comment on "Entropy production and the second law of thermodynamics: An introduction to second law analysis," by Thomas V. Marcella. *Am. J. Phys.*, 62(1), 92.

Samiullah, M. (2007). What is a reversible process? *Am. J. Phys.* 75(7), 608–609.

Tobin, M. C. (1969). Engine efficiencies and the second law of thermodynamics. *Am. J. Phys.*, 37(11), 1115–1117.

Viglietta, L. (1990). 'Efficiency' in the teaching of energy. *Phys. Educ.*, 25, 317–321.

Wallingford, J. (1989). Inefficiency and irreversibility in the Bucher diagram. *Am. J. Phys.*, 57(4), 379–381.

Yan, Z. & Chen, J. (1990). Modified Bucher diagrams for heat flows and works in two classes of cycles. *Am. J. Phys.*, 58(4), 404–405.

Yan, Z. & Chen, J. (1992). New Bucher diagrams for a class of irreversible Carnot cycles. *Am. J. Phys.*, 60(5), 475–476.

TOMAŽ KRANJC
NADA RAZPET
Faculty of Education, University of Ljubljana, Ljubljana, Slovenia
Faculty of Education, University of Primorska, Koper, Slovenia

sciED
Scientia in educatione 8(Special Issue), 2017
p. 223–229
ISSN 1804-7106

Using Online Interactive Physics-based Video Analysis Exercises to Enhance Learning

Priscilla W. Laws, Robert B. Teese, David P. Jackson,
Maxine C. Willis, Kathy Koenig

Abstract

As part of our new digital video age, physics students throughout the world can use smart phones, video cameras, computers and tablets to produce and analyze videos of physical phenomena using analysis software such as Logger Pro, Tracker or Coach. For several years, LivePhoto Physics Group members have created short videos of physical phenomena. They have also developed curricular materials that enable students to make predictions and use video analysis software to verify them.

In this paper a new LivePhoto Physics project that involves the creation and testing of a series of Interactive Video Vignettes (IVVs) will be described. IVVs are short web-based assignments that take less than ten minutes to complete. Each vignette is designed to present a video of a phenomenon, ask for a student's prediction about it, and then conduct on-line video observations or analyses that allow the user to compare findings with his or her initial prediction. The Vignettes are designed for web delivery as ungraded exercises to supplement textbook reading, or to serve as pre-lecture or pre-laboratory activities that span a number of topics normally introduced in introductory physics courses. A sample Vignette on the topic of Newton's Third Law will be described, and the outcomes of preliminary research on the impact of Vignettes on student motivation, learning and attitudes will be summarized.

Key words: video analysis, interactive curricular materials, web-based assignments.

INTRODUCTION

Video expositions are already available to help students solve problems, listen to lectures, view demonstrations, and perform virtual laboratory experiments. Although video analysis is becoming popular, materials that combine short video expositions with data collection and the analysis of real phenomena are not yet widely available. The Interactive Video Vignette project (a.k.a. IVV project) involves the creation of a new genre of educational materials. Information on how each student interacts with a Vignette can be tracked automatically, so PIs are acquiring a large body of data on how students interact with a Vignette with regard to: (1) preconceptions; (2) data interpretation abilities; and (3) conclusions. This ongoing research enables the IVV team and others to revise Vignettes to render them then more effective.

As a result of funding from the U.S. National Science Foundation [1] The *Live-Photo Physics Group* (Muller, 2008) is working on the creation and testing of about 25 short single-topic video expositions. A typical Vignette, designed to take students less than ten minutes to complete, starts by asking students to observe a video of a phenomenon and formulate preliminary predictions about it. After observing to phenomenon more carefully, sometimes in slow motion, or using video analysis to make associated measurements, students are invited to draw conclusions. A physics instructor then summarizes the outcomes of the experiment and briefly discusses how the experimental results exemplify a particular law or phenomenon.

Each vignette is designed for web delivery to supplement textbook reading or serve as a pre-lecture or pre-laboratory activity. These Vignettes are designed to address topics covered in introductory physics courses that can be illuminated with videos and address student learning difficulties identified by Physics Education Research and Cognitive Science (Roth, 1985; [2]). This four-year project began in late 2011. Vignettes that are slated to be available for use by teachers and publishers during 2014 at the comPADRE website [3] are listed in Table 1.

Table 1: Interactive Video Vignettes slated for distribution in 2014

Projectile Motion	Newton's First Law
Ball Toss Dynamics	Newton's Second Law
Slinky Drop Dynamics	Newton's Third Law
Ball Drop	Bullet/block experiment

A SAMPLE VIGNETTE ON NEWTON'S THIRD LAW

In order to give readers a better idea of what a Vignette is like, we have chosen to describe our Vignette on Newton's Third Law. This law can be stated quite simply.

> **Newton's Third Law:** *If one object is exerting a force on a second object, then the second object is also exerting a force back on the first object. The two forces have exactly the same magnitude but act in opposite directions.*

But, we know from the outcomes of physics education research that even when introductory physics students can recite Newton's Third Law, very few of them believe it (Maloney, 1984; Boyle & Maloney, 1991).

Our Vignette on the Third Law provides a dramatic demonstration of the difficulties students and other people have in understanding this simply stated Law. The Vignette features a series of "person on the street interviews" which demonstrate that most people do not believe Newton's 3rd Law, whether or not they have taken introductory physics.

The Vignette starts by asking several interviewees independently what the interaction forces would be like if two identical carts move toward each other at the same speed and collide. Every person who was interviewed said the forces would be equal and opposite. Our "professor" who interviewed people individually did so by showing a video of carts outfitted with forces probes colliding. This video display allowed each person who was interviewed to confirm whether or not he or she was correct.

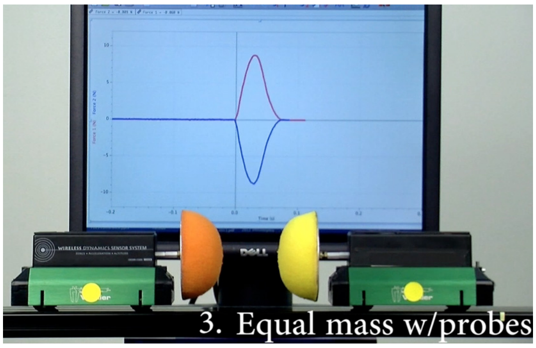


Figure 1: Two identical carts move toward each other at the same speed, collide and then recoil. Force probes readings show that the interaction forces have equal magnitudes on a moment-by-moment basis

In order to consider a more complicated situation that tests people's belief in the Third Law, the professor showed interviewees a video of a real head on car crash in which a larger, faster car collides with a smaller slower car.

Figure 2: Video frames of two cars undergoing a head on collision

When these interviewees are asked to predict whether there were differences in the interaction forces, if the car on the left has more mass *and* is moving faster. The IVV team found that ten out of eleven people, who were asked if the forces were different, predicted that the faster more massive car exerts more force on the slower less massive car. The only interviewee who made the "correct prediction" turned out to be a recent secondary school graduate who had just passed an advanced placement examination in physics — not a typical "person on the street" and was, most probably, an above average physics student.

Since there were no force sensors on the real cars, we showed our interviewees a collision between a cart with extra mass loaded on it and a slower, less massive cart. These interviewees were asked to predict the relative size of interaction forces when one object has more mass than the other *and* is moving faster. Ten out of eleven of them predicted that the faster more massive cart exerts more force on the slower less massive cart. Next we proceeded to show each interviewee a video of a more massive faster lab cart outfitted with a force sensor exerting an equal and opposite force on a slower, less massive cart that was also outfitted with a force sensor. This result is illustrated in Figure 3.

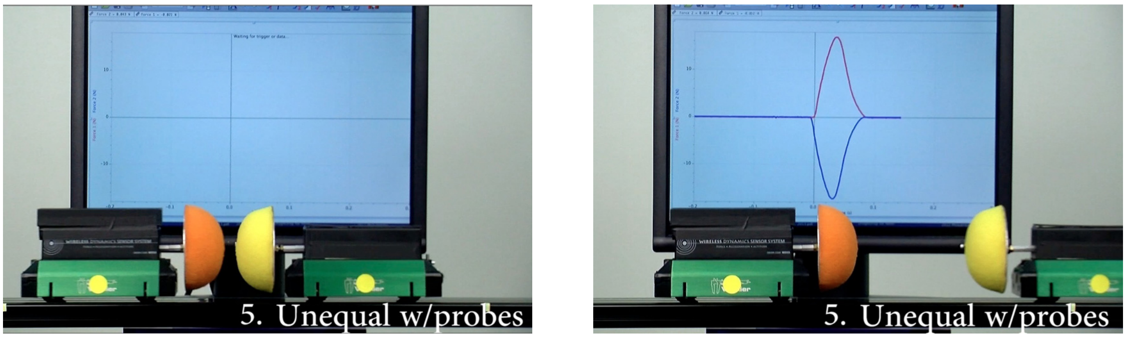


Figure 3: The two video frames show cars of unequal mass just before and after a head on collision. Before the collision the carts move toward each other at the same speed. After the collision the more massive cart on the left slows down while less massive cart on the left recoils to the right very rapidly

Since the lighter cart recoiled rapidly, it is obvious that in a real situation the driver in the lighter car would feel much more impact. If the passengers are not wearing seat belts, we are also able to demonstrate that the passenger in the slower moving and lighter cart will suffer more damage. This is in spite of the fact that Newton's Third Law still holds for the contact forces between the fronts of the carts!! However, our interviewees intuition is correct — the driver in the smaller, slower cart will indeed be at more risk for injury even though the interaction forces between the two colliding carts are the same! This demonstrates that common beliefs about forces in this situation are generally wrong. However, the driver in the smaller car is still at a higher risk for injury! This is shown in Figure 4 that displays the more massive cart on the left hitting the less massive cart on the right. The rapid recoil of the right cart jolts its driver who falls forward.

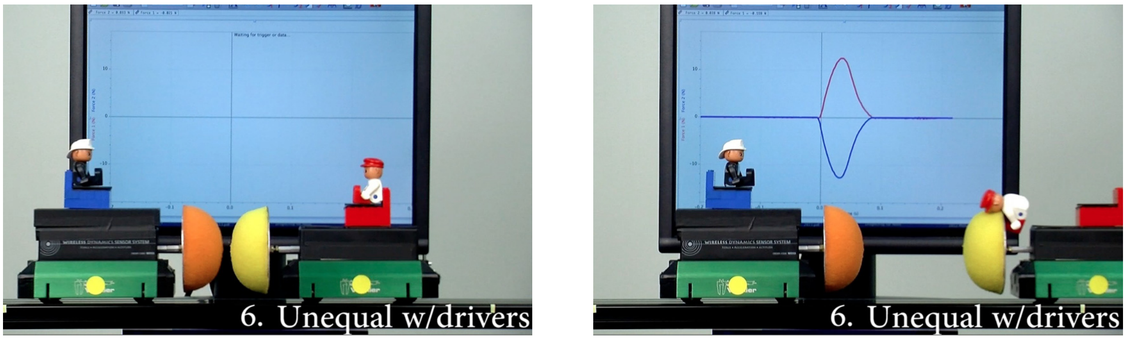


Figure 4: Video frames showing the unequal mass cars and their "drivers" just before and after a head on collision. The driver in the less massive cart shown of the right falls over while the other driver on the left merely slides forward a bit

Preliminary Research on IVV Use

Since Interactive Video Vignettes are being designed to address scientific phenomena and principles that many students tend to misunderstand, the *LivePhoto Group* recommends that instructors arrange to give their students credit for *completing a Vignette*. But, our group did not feel that student predictions and other answers to questions should be graded. This led the group to conduct research on how to motivate students to do a vignette that is "assigned by an instructor".

Although the Rochester Institute of Technology and Dickinson College students tested some of the Vignettes, most of the early motivation research was done at the University of Cincinnati in the Winter and Spring Quarters of 2011 and 2012.

1. In the winter quarter 610 students taking one of the sections of calculus-based introductory physics received an email suggesting that they view IVV on Projectile Motion as an optional homework assignment to "help them understand the topic better". *Only 28 % of students completed the "suggested" IVV.*
2. In the spring quarter 127 students in one of the sections of calculus-based introductory physics received an email suggesting that viewing the IVV on Projectile Motion IVV as an optional homework assignment would help them understand the topic better AND that there would be a related **exam** question. *This time 39 % of the students completed the IVV.*
3. In another section at the University of Cincinnati the final exam included a question on the nature of the vertical component of motion associated with the trajectory of a projectile. It turned out that 92 % of the students who had completed the projectile motion IVV answered an exam question about the vertical component of the projectile's motion correctly. On the other hand, only 71 % of the students who *didn't complete the related IVV* answered the vertical motion question correctly.

A new project involving the impact of student use of IVVs on Projectile Motion and Newton's three laws of motion is underway in introductory classes at University of Cincinnati, Rochester Institute of Technology and Dickinson College. In this study students are being given homework credit for completing each of the four vignettes but not graded on their answers. A pre- and post- test is being administered to the participating students at all three institutions with questions of each of the four topics.

Students who complete IVVs seem to enjoy them. Some of the *optional comments* collected from students as part of completing their IVV assignments during the Spring of 2012 at the University of Cincinnati include:

> "There should be more videos like this to understand concepts."
>
> "Worked Great! Informative and easy to understand!"
>
> "Great! Good way to show proof of concept, I would like for every chapter to have one of these."
>
> "It would be good if there was closed captioning on the video for the hearing impaired."
>
> "GREAT VIDEO!!! WOOOHOOO PHYSICS!!!"
>
> "I thought the interactive video was very well made. I can't wait to see and learn more."

CONCLUSIONS

Members of the *LivePhoto Physics Group* who have participated in the design and testing of the Interactive Video Vignette Project remain enthusiastic about the potential of Video Vignettes as a viable alternative to on-line lectures and other on-line teaching modalities that are primarily passive. In addition, our group is optimistic that ongoing research on the effectiveness of IVVs on other topics will prove to be superior to many conventional out-of-class assignments and in some cases augment or replace other types of out-of-class learning experiences.

Readers who would like to try NSF supported IVVs can access the collection on the comPADRE website (http://www.compadre.org/ivv/). Currently the authors are working with Cengage to create an extended series of IVVs to be widely disseminated in the future.

REFERENCES

Boyle, R. K. & Maloney, D. P. (1991). Effect of written text on usage of Newton's third law. *J. Res. Sci. Teach.*, 28(2), 123–140. [5]

Maloney, D. P. (1984). Rule-governed approaches to physics: Newton's third law. *Phys. Educ.*, 19(1), 37–42. [4]

Muller, D. A. (2008). *Designing effective multimedia for physics education* [Dissertation thesis]. U of Sydney.

Roth, K. J. (1985). Conceptual Change Learning and Students' Processing of Science Texts. In *Annual Meeting of the American Educational Research Association.*

NOTES

[1] Supported by NSF grants DUE-1122828 and DUE-1123118.

[2] The LivePhoto Physics group includes Priscilla Laws, David Jackson & Maxine Willis (Dickinson College), Robert Teese (Rochester Institute of Technology), Patrick Cooney (Millersville University), and Kathy Koenig (University of Cincinnati). A collection of educational videos is available on the group's website http://livephoto.rit.edu/

[3] As materials become available they can be accessed at http://www.compadre.org/

[4] More than 100 university students with different background in physics were asked to compare the forces that two interacting objects exerted on each other. About 2/3 of the students thought that they would be of different magnitude in some circumstances.

[5] The investigators examined the beliefs about Newton's third law of 100 university students before instruction. Half of the students were given a handout describing forces with explicit statements of the third law. No student without the handout applied the third law correctly and of those with the handout, fewer than half applied it correctly.

Priscilla W. Laws
David P. Jackson
Maxine C. Willis
Dickinson College, Carlisle PA, United States

Robert B. Teese
Rochester Institute of Technology, Rochester, NY, United States

Kathy Koenig
University of Cincinnati, Cincinnati, OH, United States

Scientia in educatione 8(Special Issue), 2017
p. 230–237
ISSN 1804-7106

Effect of Collaborative Learning in Interactive Lecture Demonstrations (ILD) on Student Conceptual Understanding of Motion Graphs

Erees Queen B. Macabebe, Eleanor Alma D. Jugueta

Abstract

To assess effectively the influence of peer discussion in understanding concepts, and to evaluate if the conceptual understanding through Interactive Lecture Demonstrations (ILD) and collaborative learning can be translated to actual situations, ten (10) questions on human and carts in motion were presented to 151 university students comprising mostly of science majors but of different year levels. Individual and group predictions were conducted to assess the students' pre-conceptual understanding of motion graphs. During the ILD, real-time motion graphs were obtained and analysed after each demonstration and an assessment that integrates the ten situations into two scenarios was given to evaluate the conceptual understanding of the students. Collaborative learning produced a positive effect on the prediction scores of the students and the ILD with real-time measurement allowed the students to validate their prediction. However, when the given situations were incorporated to create a scenario, it posted a challenge to the students. The results of this activity identified the area where additional instruction and emphasis is necessary.

INTRODUCTION

Lecture is more often than not the most common method in teaching introductory physics. It has a relatively standard format: the teacher introduces the concept in class, solve sample problems, give practice problems to students and then give a test to assess student learning. Traditional physics instruction tends to lead students to focus more on the mathematical aspects of physics rather than on deeper conceptual understanding. It also fails to provide an active learning experience, which is essential to student learning.

One strategy that has been found effective in improving students' conceptual understanding is through interactive learning demonstrations (ILD). Various studies conducted by Thornton and Sokoloff have shown that ILDs enhance conceptual learning by motivating students to generate their own predictions and collaborate with their peers by explaining their predictions (Thornton & Sokoloff, 1990, 1997, 1998, 2004). This engages the students to be more involved in their learning and helps them address their own misconceptions.

In most ILDs, the demonstration is set-up in front of the class with the computer display projected on a screen. The demonstration is then described to the students and they are asked to predict the outcome of the demonstration. After their prediction, the demonstration is then performed. The students immediately validate their answers whether or not they are correct by reconciling their predictions based on their observation of the demonstration.

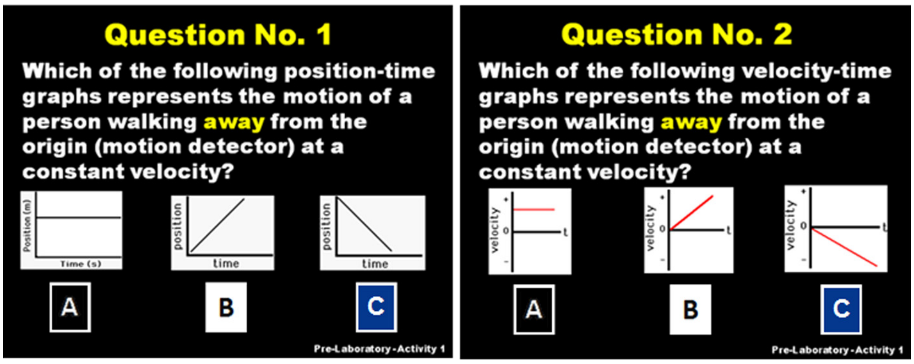
In this study, group prediction was also employed after the individual predictions to further increase student learning of physics concepts. Before the demonstration, the students were divided into pairs or groups to discuss their individual predictions. Discussion with peers helps students learn about their own cognition given a situation. It also helps them search for alternative explanations of their predictions and modify their own thinking. Collaborative learning enhances student learning because it makes them conscious of their own thought process and helps them see how others perceive the same situation (Slavin, 1983). However, not all collaborative learning activities will result in positive learning gains. In attaining the group goal, some group discussions may be influenced by a more dominant member who does not necessarily have the correct answer. Thus, group members must be encouraged to give their maximum effort to ensure effectiveness of collaborative learning.

This study aims (1) to assess effectively the influence of peer discussion in understanding concepts presented in Interactive Lecture Demonstrations (ILD) and (2) to evaluate if the conceptual understanding through ILDs and collaborative learning can be translated to actual situations such as in human and objects in motion.

INTERACTIVE LECTURE DEMONSTRATIONS

The ILD designed for this study followed the procedure: (1) description of the demonstration, (2) prediction — individual and group predictions were conducted with each group composed of 2 or 3 students, (3) demonstration (4) discussion of results, and (5) assessment.

Human motion and cart in motion were the two set-ups considered in the ILD. Three situations were presented: (1) a person walking away from or toward the origin, (2) a cart given an initial gentle push or strong push, and (3) a mass attached



Question No. 1

Which of the following position-time graphs represents the motion of a person walking away from the origin (motion detector) at a constant velocity?

A **B** **C**

Pre-Laboratory-Activity 1

Question No. 2

Which of the following velocity-time graphs represents the motion of a person walking away from the origin (motion detector) at a constant velocity?

A **B** **C**

Pre-Laboratory-Activity 1

Figure 1: The slides for human motion showing how the questions were presented to the students during the individual and the group prediction

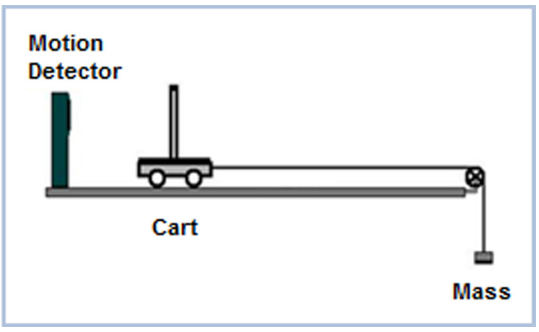


Figure 2: Set-up for cart in motion showing the mass attached to the cart

to the cart and then the cart is released from rest. Ten (10) questions on the motion graphs of these situations were asked during the individual and group prediction. Figure 1 contains two slides with questions pertaining to human motion graphs. It shows how the questions and the situations were presented to the students. Figure 2 is the diagram shown to the students to illustrate the third situation.

In the individual prediction, the students were asked to choose from a given set of graphs the one which represents the motion being described. They were then grouped and the same slides with the question and the choices were shown. This time the students were allowed to discuss their individual prediction and based on their discussion, they were required to come up with a common answer.

To understand the different motion graphs and, to analyze and interpret the motion graphs, real-time data acquisition tools were utilized in the ILD. A motion sensor interfaced to a computer with LoggerPro$^{\text{TM}}$ via LabPro$^{\text{TM}}$ was used to obtain the motion graphs. During the lecture demonstration, the position vs. time (p-t) and the velocity vs. time (v-t) graphs of each situation were plotted. The real-time graphs provide the correct answer to the prediction question. A discussion of the graphs and analysis of the motion in relation to the graphs followed after each demonstration.

To evaluate the conceptual understanding of the students, an assessment that integrates the ten situations into two scenarios was given. This was conducted immediately after the ILD so no reinforcement or in-class discussions were conducted prior to assessment. In the assessment, they were asked to draw the p-t and the v-t graphs.

The first scenario was described as follows: A person (1) walks from the detector slowly and steadily for 6 sec, (2) then stands still for 6 sec, (3) and then walks toward the detector steadily about twice as fast as before. The set-up for the second

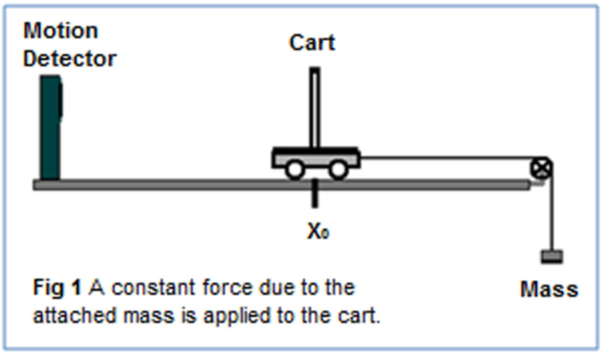


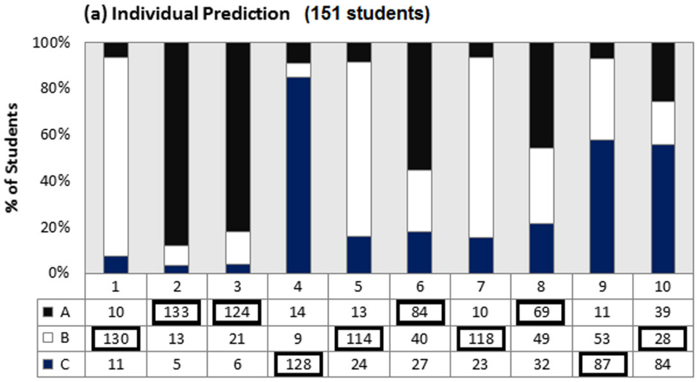
Figure 3: Illustration and caption of the second scenario in the final assessment

scenario is shown in Figure 3 where a string with a hanging mass at one end was attached to a cart giving it a constant force. The scenario was described as: the cart was given an initial push towards the left. (1) At t_0, the cart is at x_0 and moves toward the motion detector from t_0 to t_1. (2) Then, the cart moves away from the motion detector from t_1 and is back at x_0 at t_2, (3) Passing through x_0, continues to move away from the motion detector until t_3.

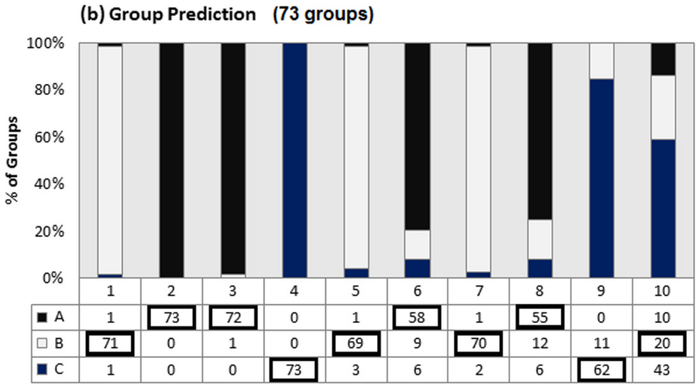
The ILD and the corresponding assessment were administered to 151 university students comprising mostly of science majors but of different year levels. This was conducted within the first week at the beginning of their first Physics course in the university. Thus, we assume that the students did not receive introductory lecture on motion graphs prior to the ILD.

Individual and group predictions

Analysis of the results shows a significant increase in the number of correct answers after peer discussion. Figure 4 shows the graphs of (a) the percentage of students and their answer in each item in the individual prediction and (b) in the group prediction. In human motion, questions 1 and 2 are shown in Figure 1, and questions 3 and 4



	1	2	3	4	5	6	7	8	9	10
■ A	10	$\boxed{133}$	$\boxed{124}$	14	13	$\boxed{84}$	10	$\boxed{69}$	11	39
□ B	$\boxed{130}$	13	21	9	$\boxed{114}$	40	$\boxed{118}$	49	53	$\boxed{28}$
■ C	11	5	6	$\boxed{128}$	24	27	23	32	$\boxed{87}$	84



	1	2	3	4	5	6	7	8	9	10
■ A	1	$\boxed{73}$	$\boxed{72}$	0	1	$\boxed{58}$	1	$\boxed{55}$	0	10
□ B	$\boxed{71}$	0	1	0	$\boxed{69}$	9	$\boxed{70}$	12	11	$\boxed{20}$
■ C	1	0	0	$\boxed{73}$	3	6	2	6	$\boxed{62}$	43

Figure 4: Plots of the percentage of students who answered either A, B, or C, in each question (x-axis), (a) in the individual prediction and (b) in the group prediction. The boxed numbers indicate the correct answers

asked the students to choose the *p*-*t*, and the *v*-*t* graphs, respectively, of a person walking towards the motion detector. From an average of 85.26 % in the individual prediction, the average number of correct answers increased to 99.01 % after peer discussion, an improvement of 16.12 %.

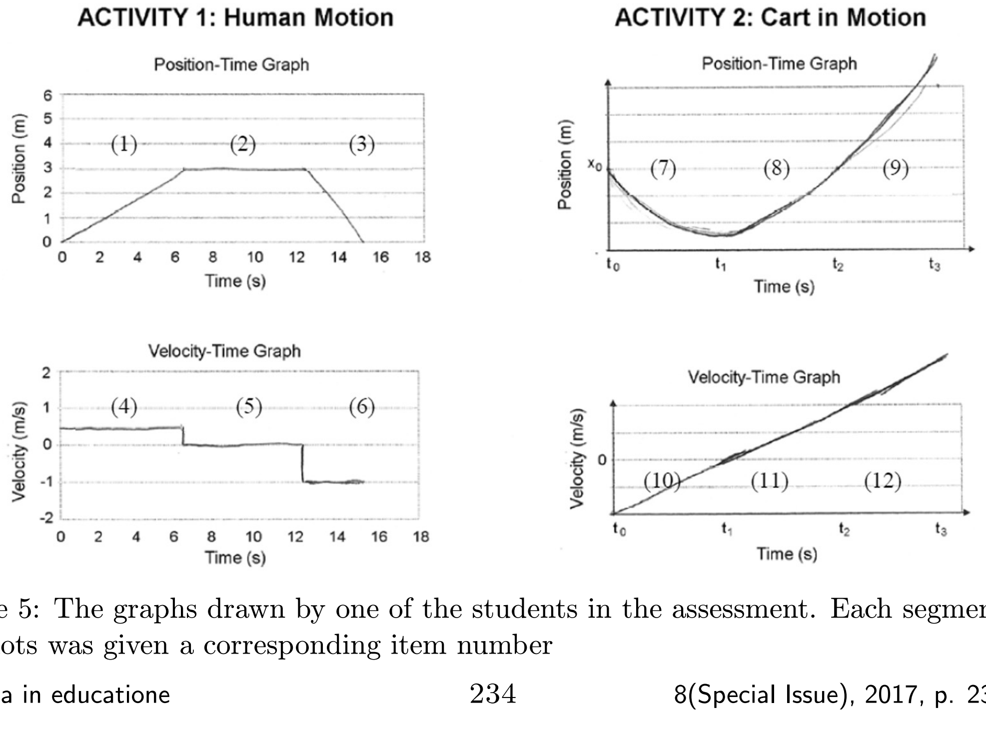
From the individual prediction, many found difficulty in visualizing the *v*-*t* graph of an object given an initial push (questions 6 and 8) moving along a frictionless track as described by the second situation. It is possible that the students failed to connect the meaning of "initial push" in this situation. Thus, their answers to the questions were derived from a possible misconception which implies that an external force is always present in this scenario. The said external force can be due to the initial force which, by Newton's Laws of Motion, causes the object to accelerate thereby increasing the velocity of the cart. After the group discussion, the number of students with correct answers in these questions increased by 23.18 % and 29.80 %, respectively.

Questions 9 and 10 pertain to the third situation shown in Figure 2. Of the 87 who answered (C) nonlinear increase in question 9, the *p*-*t* plot of the cart, only 17 answered (B) linear increase in question 10 which asked for the *v*-*t* plot of the motion. After the group discussion, there is a significant improvement in the number of correct answers in question 9, 85.43 % from 57.62 %. However, the increase in question 10 is only 9.27 %, from 18.54 % to 27.81 %. Also, of the 17 who got the correct answer in question 10 in the individual prediction, 5 changed their answers in the group prediction. It means that these students were not confident with their answer and was easily convinced by their peer in the group prediction. Overall, however, the improvements observed in the total score of the groups and the item scores seen in Figure 4 indicate the positive effect of collaborative learning.

ASSESSMENT

The achievement gain between prediction and assessment were obtained and analyzed. In the assessment, some items were similar to the situations given in the prediction and ILD. They were the basis for the achievement gain analysis.

Figure 5 shows the assessment sheet with the correct answers. In Figure 6, the graph of the percentage of students with correct and incorrect answers in the final assessment is presented. The segments of the motion graphs in Figure 5 were


ACTIVITY 1: Human Motion

ACTIVITY 2: Cart in Motion

Figure 5: The graphs drawn by one of the students in the assessment. Each segment of the plots was given a corresponding item number

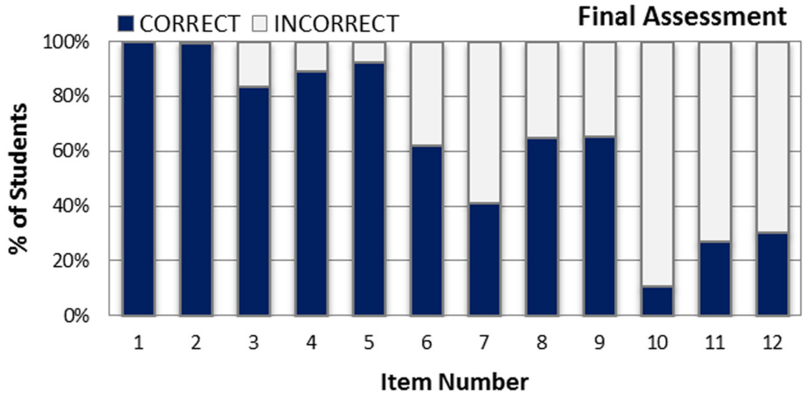


Figure 6: The graph of the percentage of students with correct and incorrect answers for each item in the final assessment

Table 1: Mapping of the items in the assessment that correspond to or is similar to the questions in the prediction part of the ILD, the percentage of students with correct answers and the achievement gain for each corresponding items

Item	**1**	**3**		**4**	**6**		**8**	**9**	**11**	**12**
Assessment (%)	100	83.44		89.40	62.25		64.90	65.56	27.15	30.46
Question	**1**	**3**	**6**	**2**	**4**	**7**	**9**		**10**	
Ind. Prediction (%)	86.09	82.12	55.63	88.08	84.77	78.15	57.61		18.54	
***Gain (%)**	**13.91**	**1.32**	**27.81**	**1.32**	**−22.52**	**−15.90**	**7.28**	**7.95**	**8.61**	**11.92**

*Gain = (Assessment − Ind. Prediction)

assigned a number which corresponds to the x-axis of the graph in Figure 6. Table 1 shows the items in the assessment that correspond to or are similar to the questions in the prediction part of the ILD. Also, the percentage of the number of students with correct answers in the assessment and in the individual prediction are shown in the table, as well as the achievement gain for each corresponding items.

Assessment item 3 (see Figure 5) corresponds to prediction questions 3, which pertains to the trend of the p-t plot, and 6, which pertains the magnitude of the plot when the velocity is doubled. The same goes with items 6, questions 4 and 7 but they refer to v-t plots. In assessment item 3, 10.60 % of the students' answer have the correct trend (linear, + y-axis, − slope) but incorrect magnitude of the slope. If we take this into account, then the achievement gain between item 3 and question 3 is actually 11.92 %.

In item 6, the achievement gains from questions 4 and 7 are both negative. Although 100 % and 96.03 % of the students were correct in questions 4 and 7, respectively, in the group prediction, the achievement gains are negative. The assessment shows that the students know that for constant velocity, v-t plot is a straight horizontal line. However, 18.54 % did not take into account the direction of the motion even though this was emphasized in the discussion that followed the demonstration.

In the second scenario, items 7 and 10 were introduced to evaluate if the students can already integrate the motion towards the origin while a constant force in the opposite direction is in effect. Although the percentages of correct answers in this scenario are low as seen in Figure 6, the achievement gain is positive. About 25.83–33.78 % of the students considered the p-t plot to be linear, which was the common mistake in these items. In the v-t plot, 39.07 % of the students represented

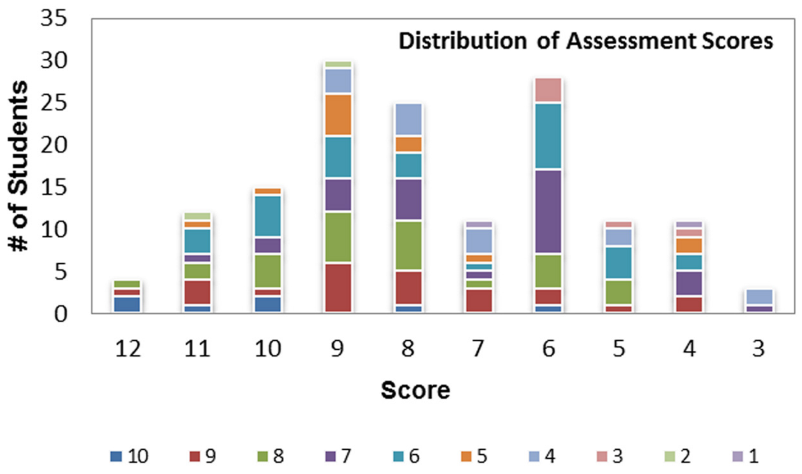


Figure 7: Plot of the raw scores that the students obtained in the assessment. The legend at the bottom of the graph indicates the raw score of the student in the individual prediction

item 10 as a linear plot with negative slope located below the x-axis. As a result, their plots in items 11 and 12 were automatically shifted although it is evident in their answers that they remember the trend of the v-t graph of the cart being pulled by the hanging mass.

Figure 7 shows the plot of the raw score the students obtained in the assessment. It also shows the raw score these students obtained in the individual prediction (indicated in the legend). The minimum score in the assessment should be four (4) since items 1, 3, 4, and 6 were in the ILD. Unfortunately, this is not the case as seen in Figure 7. Also, some students achieved negative gain between the individual prediction and the assessment scores. One possibility is that their predictions were just guesses since the choices were given and, when asked to draw the graph, they failed to interpret the motion because they did not grasp the concepts during the group discussion and even after ILD. Looking at the figure, 72.41 % who got a score of 6 were correct it items 1–6 only, while 72.73 % of those who got 7 were correct in items 8 and 9. However, their plots in items 11 and 12 were shifted down but followed the correct trend. This is also true for the v-t plots of 65.45 % of those who got a score of 8 or 9. This could indicate that those students with scores falling between 7 and 9 learned from the group discussion and the ILD but did not know how to plot the motion of item 10. In general, the assessment results show improved scores for most of the students.

Conclusion

In an Interactive Lecture Demonstration, collaborative learning produced a positive effect on the prediction scores of the students. The ILD with real-time measurement allowed the students to validate their prediction. However, when the given situations were incorporated to create a scenario, it posted a challenge to the students. The results of this activity identified the area where additional instruction and emphasis is necessary. In particular, Newton's second law of motion, in relation to the situation where the acceleration due to the applied force and the velocity of the body are in the opposite direction, needs to be elaborated.

REFERENCES

Slavin, R. E. (1983). When does cooperative learning increase student achievement? *Psychological Bulletin*, 94, 429–445.

Thornton, R. K. & Sokoloff, D. R. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics*, 58 (9), 858–867.

Thornton, R. K. & Sokoloff, D. R. (1997). Using interactive lecture demonstrations to create an active learning environment. *The Physics Teacher*, 35(6), 340–347.

Thornton, R. K. & Sokoloff, D. R. (1998). Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, 66(4), 336–352.

Thornton, R. K. & Sokoloff, D. R. (2004). *Interactive lecture demonstrations: Active learning in introductory physics.* Hoboken, NJ: Wiley.

EREES QUEEN B. MACABEBE
Department of Electronics, Computer and Communications Engineering, Ateneo de Manila University, Loyola Heights, Quezon City 1108 Philippines

ELEANOR ALMA D. JUGUETA
Computer Science Department, Faculty of Engineering, University of Santo Tomas, España Blvd., Manila 1008 Philippines
Department of Physics, Ateneo de Manila University, Loyola Heights, Quezon City 1108 Philippines

Scientia in educatione 8(Special Issue), 2017
p. 238–246
ISSN 1804-7106

Chaos at High School

Tamás Meszéna

Abstract

We are faced with chaotic processes in many segments of our life: meteorology, environmental pollution, financial and economic processes, sociology, mechanics, electronics, biology, chemistry. The spreading of high-performance computers and the development of simulation methods made the examination of these processes easily available. Regular, periodic motions (pendulum, harmonic oscillatory motion, bouncing ball), as taught at secondary level, become chaotic even due minor changes. If it is true that the most considerable achievements of twentieth century physics were the theory of relativity, quantum mechanics and chaos theory, then it is presumably time to think about, examine and test how and to what extent chaos can be presented to the students. Here I would like to introduce a 12 lesson long facultative curriculum framework on chaos designed for students aged seventeen. The investigation of chaos phenomenon in this work is based on a freeware, "Dynamics Solver". This software, with some assistance from the teacher, is suitable for classroom use at secondary level.

Key words: chaotic process, numerical simulation, nonlinear oscillators, Dynamics Solver.

INTRODUCTION

It was a common opinion at the end of the 19th century that, in physics, what could be found out, it had been done. For this reason, the young Max Planck was advised by his teacher to choose some other profession, not physics (Planck, 1958). However, it didn't take more than a few years, and a convincing reply was given to this thoughless opinion. Since then no physicist would think that physics will ever be fully known. Nevertheless, it seems, the same mistake has been made again and again. At the end of the 20th century, perhaps, not many people expected any discoveries in classical physics. But chaos theory is just such a thing.

TEACHING CHAOTIC PHENOMENA AT HIGH SCHOOL

WHY TO TEACH CHAOS AT HIGH SCHOOL?

Chaos, in mechanical motion, for example, is not just a scientific peculiarity. In contrast, chaotic motion is found nearly everywhere, if our world is investigated in fine detail.

"From 20th century science three concepts will be remembered only: theory of relativity, quantum mechanics and chaos theory." wrote James Gleick in his book, Chaos (Gleick, 1988). It might be an exaggeration to some extent, since while the first two theories brought new equations of motion, basically, the theory of chaos revealed new depths of an equation of motion known for a long time. The fundamental observations of the first two theories (born 90–110 years ago) have been incorporated in secondary education curriculum. The real development of chaos theory started some 30 years ago. The investigation of chaotic phenomena has brought such a fundamental change in the interpretation of nature, that is undoubtedly reasonable and, luckily, possible to deal with in secondary education. However, very few secondary school text book includes these subjects. In Hungary, actually, there is none at all. For this reason, a syllabus suitable for facultative classes is suggested in this work.

Regular motions tought in secondary school, strictly speaking, do not exist in nature. They can be treated as exceptions, perhaps. Chaotic motion is widely spread. It takes an eager pupil to follow text book concepts enthusiasticly. Others loose interest towards physics partly due to the many simplifying assumptions made (needed be able to describe motion mathematically). As a result, pupils do not feel that their real-life observations would be delt with in physics classes. It is a real joy to both teacher and pupils when such a subject is lectured that is possible to observe in nature approximately in the same way as in the theory.

Chaos is interesting, beautiful and it has the sense of mistery. Features that come very useful in education. Some of the first occasions when the subject is mentioned for an average pupil probably include the chaos researcher, a main character of Steven Spielberg‘s film, Jurassic Park, or the fractals of sprawling plants mimicing human soul in Paul Young's novel, The Shack.

In Figure 1 the path of a magnetic pendulum above a plane containing three attractive magnets can be seen. Figure 2 shows the complex geometric structure characteristic of chaos in the mixing process of dyes.

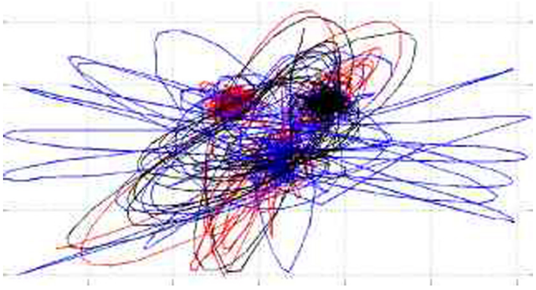


Figure 1: Path of a magnetic pendulum

Figure 2: Chaotic mixing of dyes

What to teach from chaos theory?

Let us consider a few simple examples where regular motion studied at school becomes chaotic with little modification. Pendulum motion shows this behaviour. The motion of a simple pendulum is regular. However, if the point of suspension is moved periodically (driven pendulum), or two pendulums are coupled (double pendulum), or magnets are placed next to the pendulum (magnetic pendulum), see Figure 3, the motion becomes typically chaotic.

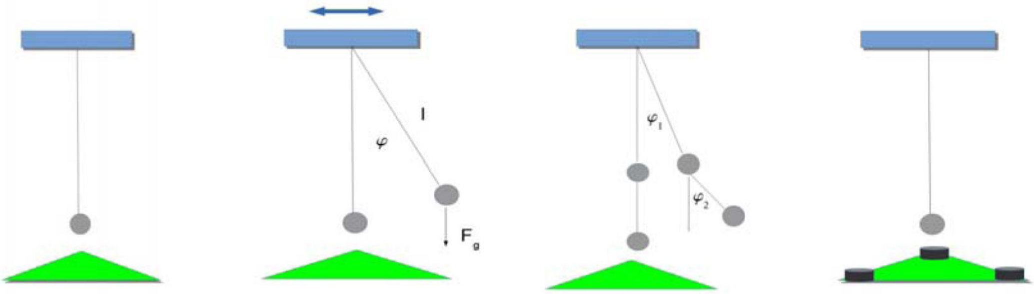


Figure 3: Mathematical pendulum, driven pendulum, double pendulum, magnetic pendulum. The latter three systems are chaotic

Another example of a simple regular motion is a bouncing ball on the table. A bouncing ball on an oscillating plate, on a double edge or on stairs (Figure 4) may turn to be chaotic.

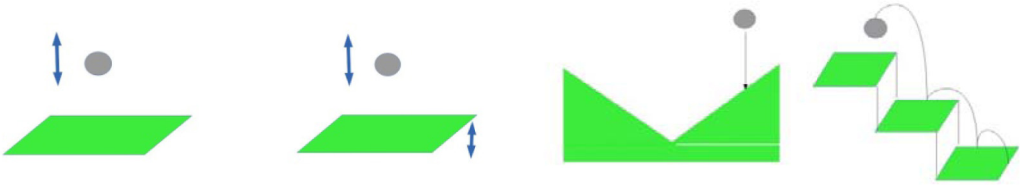


Figure 4: Bouncing ball, bouncing ball on an oscillating plate, on a double edge, on a stairway. The latter three systems are chaotic

Let us investigate the motion of a driven oscillator in detail. If a driven oscillator is based on a spring that obeys Hooke's law, the resulting motion will be a regular motion that is easy to describe. With a nonlinear spring (Figure 5), however (and real springs are never perfectly linear), motion may become much more complicated: it may show chaotic behaviour.

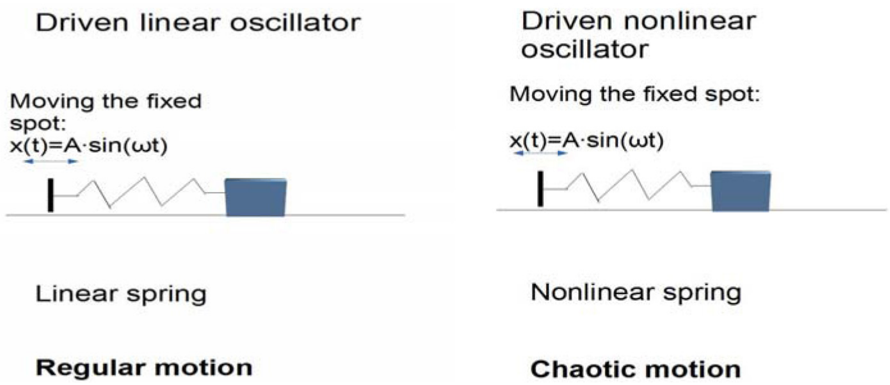


Figure 5: In spite of the identical sinusoidal driving, the motion of a body fixed to a linear spring is always regular, whereas that with a nonlinear (i.e. realistic) spring is typically chaotic

The description of chaotic motion can be well explained by the concepts used for the example of nonlinear oscillators. Regular motions are normally described in terms of position versus time, velocity versus time (and acceleration versus time) functions. In case of chaotic motions, these functions are so complicated and irregular that by graphing these functions it is hard to recognize the surprising order that is inherent in these motions. Before chaos theory appeared, such motions were simply considered irregular. A more appropriate representation is needed that reflects the properties of such motions better, and makes it possible to reveal the order underlying chaos.

No information or systematic behaviour can be deduced from the investigation of the usual functions since the periodicity of the original oscillator is entirely lost (Figure 6).

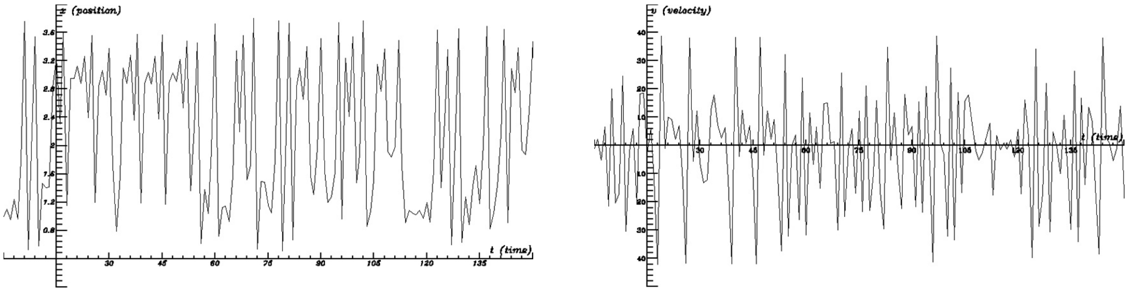


Figure 6: Position-time and velocity-time representation of a driven nonlinear oscillator

Information needs to be condensed and represented in another way. To represent chaotic motion, a velocity versus position graph (called phase space) is used, since it provides a better overview of such motions. The complicated geometrical structure, characteristic of the motion, is revealed by taking samples at regular intervals (at that of the driving period), and by plotting only these points on the plane of the phase space (Figure 7). This procedure is called a stroboscopic map.

Note that in this representation the image of a periodic motion is a single point, since the location and the velocity would be always the same, period by period. It is obvious from Figure 7 that, although chaotic motion never repeats itself, it cannot be considered completely irregular, it is not like white noise. It has a clean-cut, profound order, just a much more complex one than that of the periodic motions.

Chaos can be described as the "complex temporal behaviour of simple systems"

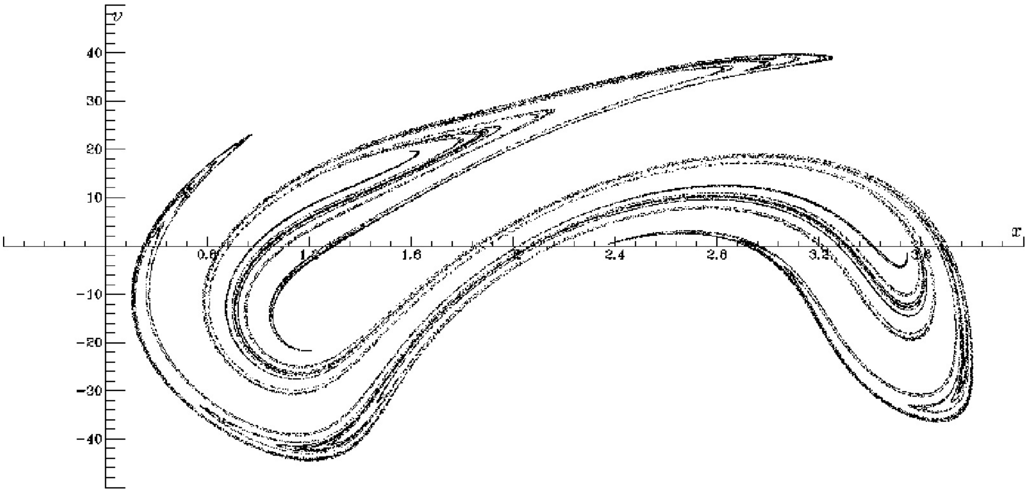


Figure 7: The stroboscopic mapping on the phase space of a driven nonlinear oscillator. This presentation exhibits the unusual pattern underlying chaotic motion

(Ott, 1993; Tél & Gruiz, 2006). It is highly instructive to realize the fact that even simple mechanical systems, known for a long time, can be chaotic.

In the following section the focus is on a method we propose to produce, in cooperation with the pupils, Figure 7, and make them understand the equation of motion used for this phenomenon.

The equation of motion for the position x of the driven nonlinear oscillator is:

$$\ddot{x} = -\omega_0^2 x + \varepsilon x^3 - \alpha \dot{x} + \mathrm{A}_0 \cos \omega t.$$

Here $\ddot{x}$ is the second time-derivative of the position, ω_0 is the frequency of the oscillator, ε is the parameter of the nonlinear spring, x' is the velocity, α is the parameter of the drag coefficient, and A_0 and ω are the amplitude and frequency of the driving, respectively.

Secondary school pupils are not aware of differential equations, most probably they don't even know what differential calculus is. However, the meaning of the above equation can be unfolded by using the concept of velocity (v) and acceleration (a) instead of time derivatives. With properly chosen units the above equation can be written in a simpler form:

$$a = -A^2 x - A^2 x^3 - Bv + C \cos(2\pi t)$$

Measuring time in units of driving period $2\pi/\omega$ and distance in suitable units, quantity a (v) represents the dimensionless acceleration (velocity). Parameters A, B and C are numbers characterizing the spring's strength, the drag and the driving amplitude, respectively. In this form the physical meaning of the four terms on the right hand side are: linear and nonlinear spring force, drag, and driving. This way a sufficient interpretation is given for the equation, even if not all details are fully explained.

For the description of various dynamics two fundamentally different methods are used:

1. Forces acting on the object are known, and the functions describing the path can be explicitly given. Everything is known, basically. Examples are motion with constant acceleration, and harmonic oscillation:

$$a = \frac{F}{m}\text{const} \Rightarrow s(t) = \frac{a}{2}t^2 + v_0 t$$
$$a = -\omega^2 y \Rightarrow y(t) = A \sin(\omega t + \phi_0)$$

The trajectory cannot be explicitly given due to nonlinear forces, it can be numerically calculated only, step by step. This is the case for chaotic motion.

A numerical solution should be performed, for example, by means of the Dynamics Solver program.

The Dynamics Solver program

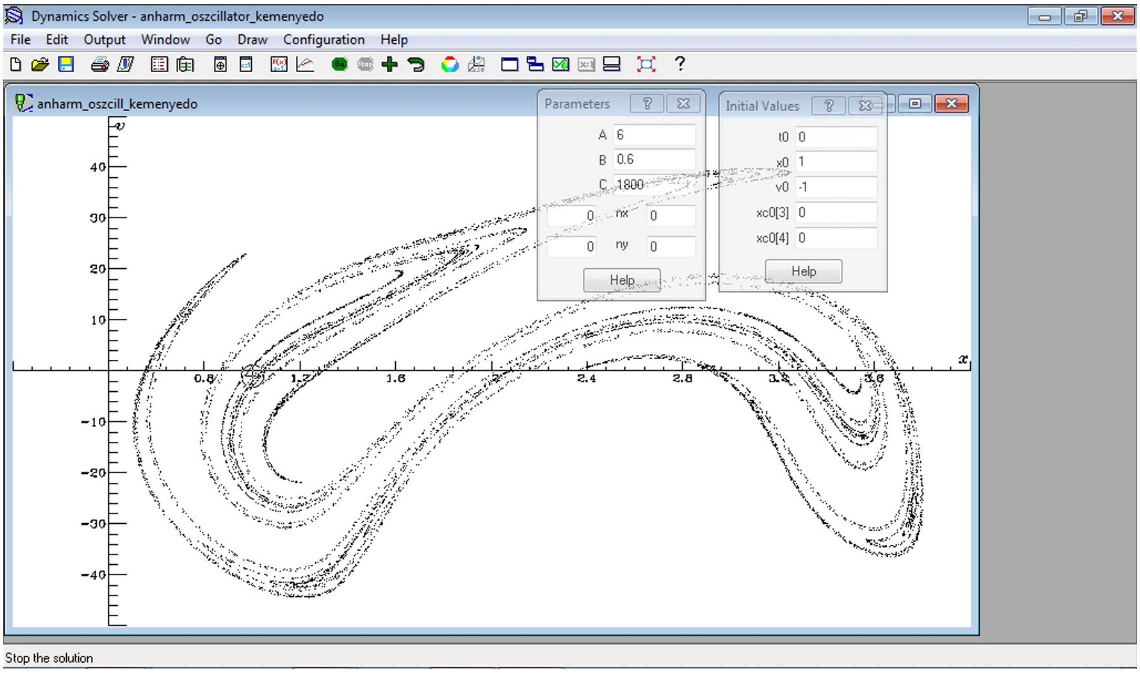
Dynamics Solver is a freeware, developed for the numerical integration of sets of differential equations by Juan M. Aguirregabiria in Spain. The software can be freely downloaded from several websites (see e.g. Dynamics Solver).

Input data for the calculations are the number of equations, the number and notation of variables, functional relationships, parameters of theequation, initial conditions, and the parameters of the visualization.

Second order equations are solved as a set of first order equations. The format of equations is the one used in secondary schools:

$$\begin{aligned}\frac{\mathrm{d}x}{\mathrm{d}t} &= v\\ \frac{\mathrm{d}v}{\mathrm{d}t} &= -A^2x - A^2x^3 - Bv + C\cos(2\pi t)\end{aligned}$$

The Dynamics Solver program starts with the screen shown in Figure 8: here the various parameters and initial values can be specified and, at the same time, the results of calculations are presented. The chaotic attractor of Figure 7 was obtained with $A = 6$, $B = 0.6$, $C = 1\,800$. The initial values were taken as $t_0 = 0$, $x_0 = 1$, $v_0 = -1$ and the simulation was run over 1 000 000 dimensionless time units. The chaotic attractor is reached after about a single time unit, the pattern seen in Figure 7 is therefore independent of the initial conditions.



A 6
B 0.6
C 1800
0 nx 0
0 ny 0

t0 0
x0 1
v0 -1
xc0[3] 0
xc0[4] 0

Figure 8: The screen of the Dynamics Solver program. The boxes in the right upper corner contain the parameters and the initial values. The data appearing with zero values in the boxes are irrelevant for our purposes

The program is user friendly, easy to understand. The only problem to overcome is the huge number of choices.

The graphs shown in Figure 7 and 8 have been produced by specifying the presented results as snapshots taken in every driving period on the x-v plane. The resulting complex shape is called the chaotic attractor. The filamentary structure of the attractor is infinitely complex, it is a fractal.

Once the necessary equations have been entered and settings have been made, it is very easy to test the effect of changing parameters and initial conditions. This can serve as the pupils' own research activity, even with the possibility of some significant achievements.

Various motions can be studied with the method described. First, motions studied in the standard curriculum should be simulated. Results already known can be checked and, at the same time, sufficient skills can be gained in using the software. Once the software is familiar, various chaotic motions can be studied.

Syllabus of a chaos-teaching program

Facultative program for 17 year old students with a sum of 12 teaching hours. The topics of the classes are the following:

Class 1-2. Introduction, demonstrating a few chaotic phenomena: chaotic pendulums, bouncing balls, driven nonlinear oscillator. Equations of motions, solving simple equations of motion. Homework: home-made chaotic tools.

Class 3-4. Examination of chaos with computer: generating chaotic attractors (of e.g. the driven pendulum), discussing the necessary concepts: chaos, phase space, stroboscopic mapping, attractors. Solving differential equations numerically by means of Dynamics Solver.

Class 5-6. Fractal properties of chaotic attractors. Mathematical fractals, interpretation of fractal dimension, examples. Physical fractals, examples from biology and geography.

Class 7-8. Examination of further chaotic phenomena, computer simulations.

Class 9-10. Computer simulations. Chaotic phenomena in other disciplines: biology, chemistry, meteorology, geography, astronomy, sociology and economy.

Class 11-12. Summary, "final assessment". Summing up experiences, discussion.

Attempts to teach chaos in Hungary and in other countries

In 2003 Ildikó Szatmári-Bajkó developed a similar chaos teaching program, based on the use of a chaotic motion simulation program, developed at the Department of Theoretical Physics of Eötvös University (Szatmári-Bajkó, 2010, 2006). In 2008 and 2010 József Jaloveczki published articles on numerically solving equations of motion with students at high schools (Eichhardt & Jaloveczki, 2008, 2009).

In Italy, I am aware of two books which mention chaotic phenomena, such as molecular and deterministic chaos (Caforio & Ferilli, 1993; Violino & Robutti, 1995). The basic characteristic features of a chaotic system are mentioned in a textbook of physics in Austria (Jaros, Nussbaumer & Kunze, 1999). Some elements of chaos theory are relatively detailed in a textbook in Romania (Tellmann, Darvay & Kovács, 2006).

CONCLUSIONS

It's worth teaching chaos theory at high school level since it gives an insight for the students into a recently discovered feature of physics, this may raise further the interest towards science. The widespread popularity of informatics also helps us to direct students towards an important field, to give opportunity of creative work, and to provide artistic facets of scientific activities.

The Dynamics Solver freeware is an appropriate program for work with students. Its use is simple and easily overcomes any lack of knowledge in math acquired in secondary school. It gives opportunity to design independent experiments and may lead to results, as well as, to aesthetic joy.

It's a striking experience seeing how the chaotic attractor of a driven nonlinear oscillator or pendulum emerges from thousands of points on the screen. The latter is shown in Figure 9.

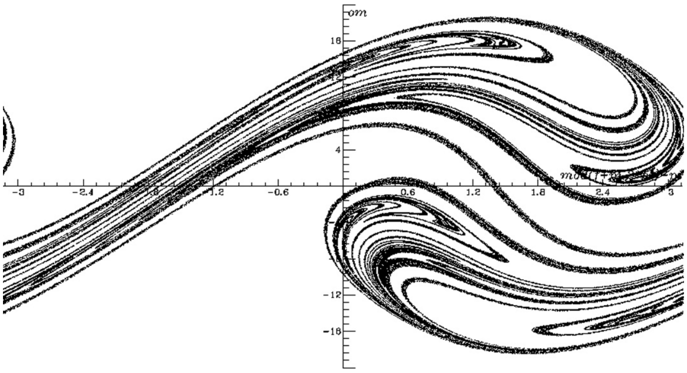


Figure 9: The chaotic attractor of a driven pendulum in the stroboscopic map generated by Dynamics Solver

The equation of motion of the driven pendulum is:

$$\ddot{\phi} = -\frac{g}{l}\sin(\phi) - \alpha\dot{\phi} + \frac{A\omega^2}{l}\cos(\omega t)\cos(\phi)$$

Measuring time in units of the driving period and distance in the unit of the pendulum's length l, three parameters remain. The dimensionless equation of motion is:

$$\ddot{\phi} = -a\sin(\phi) - b\dot{\phi} + c\cos(2\pi t)\cos(\phi)$$

Parameters a, b, c are numbers characterizing the frequency, the drag and the driving amplitude, respectively. The simulation is run with $a = 4\pi^2/9$, $b = 0.2\pi$, $c = 8\pi^2$, and with the initial values $\phi_0 = 1$ and $\omega_0 = 0$ for a time of 1 000 000 dimensionless units.

ACKNOWLEDGEMENT

Special thanks are due to my PhD supervisors Márton Gruiz and Tamás Tél for their useful pieces of advice.

REFERENCES

Caforio, A. & Ferilli, A. (1993). *Physica 2.* Firenze: Le Monier.

Dynamics Solver. Available at http://tp.lc.ehu.es/jma/ds/ds.html

Eichhardt, I. & Jaloveczki, J. (2008). Fizikázzunk egyszerûen, számítógéppel (Let's study physics the simplest way: using only a computer). *Fizikai Szemle*, 2008(9), 311–315.

Eichhardt, I. & Jaloveczki, J. (2009). Numerikus módszerek a diákköri munkában (Numerical methods in students' circle work). *Fizikai Szemle*, 2009(10), 348–351.

Gleick, J. (1988). *Chaos. Making a new science.* Penguin Books.

Jaros, A., Nussbaumer, A. & Kunze, H. (1999). *Basiswissen Physik-compact.* Wien: Öbv&hpt.

Ott, E. (1993). *Chaos in dynamical systems.* Cambridge University Press.

Planck, M. (1958). *Physikalische Abhandlungen und Vortrage.* Braunschweig: Friedrich Vieweg und Sohn.

Szatmári-Bajkó, I. (2010). Káosz, rend, látvány. *Iskolakultúra*, 2010(1), 116–131.

Szatmári-Bajkó, I. (2006). "Káoszt"? – azt! (Some chaos? Yes, let us have it!), *Fizikai Szemle*, 2006(11), 376–380.

Tél, T. & Gruiz, M. (2006). *Chaotic dynamics.* Cambridge University Press.

Tellmann, J., Darvay, B. & Kovács, Z. (2006). *Fizika XI.* Ábel Kiadó.

Violino, P. & Robutti, O. (1995). *La fisica e i suio modelli, Volume 3.* Bologna: Zanichelli.

TAMÁS MESZÉNA
Nagy Lajos High School of the Cistercian Order, 7621 Pécs Széchenyi tér 11, Hungary
Physics Education PhD Program Eötvös University, Budapest, Hungary

Scientia in educatione 8(Special Issue), 2017
p. 247–253
ISSN 1804-7106

Just How Deterring Are Formulas?

Alexander Strahl, Rainer Müller, Susan Hagendorf, Julian Grobe

Abstract

Formulas are an effective means for communication in physics. Most teachers would agree, however, that novices tend to be deterred by formulas. Up to now, this common belief has never been substantiated by quantitative research. Here we report on an attempt to identify and quantify the variables that govern the appraisal of physical formulas. In an empirical study, 684 secondary school and university students were asked to indicate for 38 formulas to which extent they perceive the formula as deterring. The result is surprisingly simple. We are able to model the responses with only a single variable: the length of the formula. An explicit model equation (saturating exponential) to fit the data can be given.

Key words: formula, unit, deterring, length of formula questionnaire study.

INTRODUCTION

Previous studies on physical formulas concentrated mainly on their role in text comprehension and problem solving. Dee-Lucas and Larkin (1988) found that undergraduate physics students judged physical texts containing formulas as more important than their verbal counterparts. The same authors found a slight advantage in text comprehension when the formulas in a physics text were replaced by verbal equivalents (Dee-Lucas & Larkin, 1991). This result was called into question by Müller and Heise (Müller & Heise, 2006), who found a significant advantage in text comprehension for secondary school students reading the version with formulas. Remarkably, most of the students interviewed by Müller and Heise expressed a positive attitude towards physical formulas, just as in Strahl et al. (2009, 2010).

The role of formulas in problem solving has been explored in the context of expert/novice research. There is evidence that experts and novices solve physics problems differently. According to Larkin et al. (1980) and Larkin (1983) novices tend to use formulas in the early stages of problem solving, while experts develop a qualitative representation before using equations.

Perhaps the most famous remark on the subject of the present note has been made by Stephen Hawking. In the preface of his popular book “A brief history of time” (Hawking, 1988), he writes: *“Someone told me that each equation I included in the book would halve the sales. I therefore resolved not to have any equations at all. In the end, however, I did put in one equation, Einstein’s famous equation* $E = mc^2$*. I hope this will not scare off half of my potential readers.”* Presumably, there are two reasons why Hawking did not fear that this particular formula would deter his readers too much: (a) he could assume the readers are familiar with it and (b) it is not too complicated.

SETTING OF THE STUDY

In our empirical study, we asked students to indicate for 38 formulas to which extent they perceived the formula as deterring. The formulas were taken from different fields of physics, with varying length and complexity. Some examples are:

$$s = \frac{a \cdot t^2}{2} \tag{1}$$

$$f = \frac{1}{2\pi\sqrt{L \cdot C}} \tag{2}$$

$$W = \int F \cdot dr \tag{3}$$

$$u_\nu(\nu, T) = \frac{8\pi v^2}{c^3} \frac{h\nu}{\mathrm{e}^{\frac{h\nu}{kT}} - 1} \tag{4}$$

$$\Delta K_{\text{kin}} = \frac{1}{2}(m_1 \cdot v_1^2 + m_2 \cdot v_2^2) - \frac{1}{2}u^2(m_1 + m_2) \tag{5}$$

We interrogated three different groups of students:
Group 1: A random sample of 288 secondary school students (grade 10 to 12),
Group 2: 258 first-year university students not majoring in physics,
Group 3: 24 physic education students for middle school,
Group 3: 114 first-year physics and electrical engineering majors.

The participants had to complete a questionnaire in which they rated each of the 38 formulas on a scale from 1 (not at all deterring) to 5 (very deterring). For quantitative modeling it is more convenient to use a scale that varies from 0 to 1. The data were thus rescaled by a linear transformation. In total, we obtained 25 992 individual ratings from the 684 participants. The group averages of these ratings define a "degree of deterrence" for the 38 formulas.

Thought

At first sight, it seems quite hopeless to predict how the students would assess the formulas. There is an abundance of factors that may affect the rating:

1. the familiarity of the students with the subject area to which the formula belongs,
2. the level of physics expertise of the students,
3. the familiarity with the formula itself or with the variables contained in it,
4. the appearance of unusual symbols (Greek letters, square roots or integral signs),
5. the length of the formula,
6. the structure of the formula (appearance of brackets, fraction bars).

Factors 1 and 3 can be controlled by inspection of the physics curricula of the different groups. The level of expertise can roughly be assessed by the group membership and the last physics grade. On the contrary, it is not entirely obvious how to define the notion "formula length". We chose the simplest definition we could think of: counting the number of symbols appearing in the formula. Any symbol, be it a letter, a number, a fraction bar, or a plus sign, contributes equally to the length. Functions like sin, cos, or exp and named indices (like the index "kin" in (5)) are counted once. For the formulas (1)–(5) shown above, we obtain a length of 8, 10, 7, 26, and 35, respectively.

Result — formula

Surprisingly the responses of each group could be modelled with a single variable: the formula length defined above. The remaining factors seem to have a much smaller influence on the degree of deterrence. Figure 1 shows the data of group 2 plotted as a function of formula length. A marked nonlinear relationship is clearly discernible. The graph suggests that the length alone appears to be a good indicator of how deterring a formula is perceived.

The data can be interpreted as follows: Short formulas are perceived as less deterring than longer ones. The relation is not linear, however. Increasing the formula length by 5 symbols has a stronger effect for a formula of length 5 than for one with length 20. The deterring effect saturates.

Saturation phenomena are known from physics and many other branches of science. Perhaps the simplest example is the charging of a capacitor. Quantitatively, these phenomena are typically described by a saturating exponential of the form $1 - \mathrm{e}^{-x}$. An analogous model appeared to be promising for the introduced correlation.

Using a nonlinear least-square method, the data was fitted to the model equation

$$y = 1 - \mathrm{e}^{-\frac{x-3}{A}}. \tag{6}$$

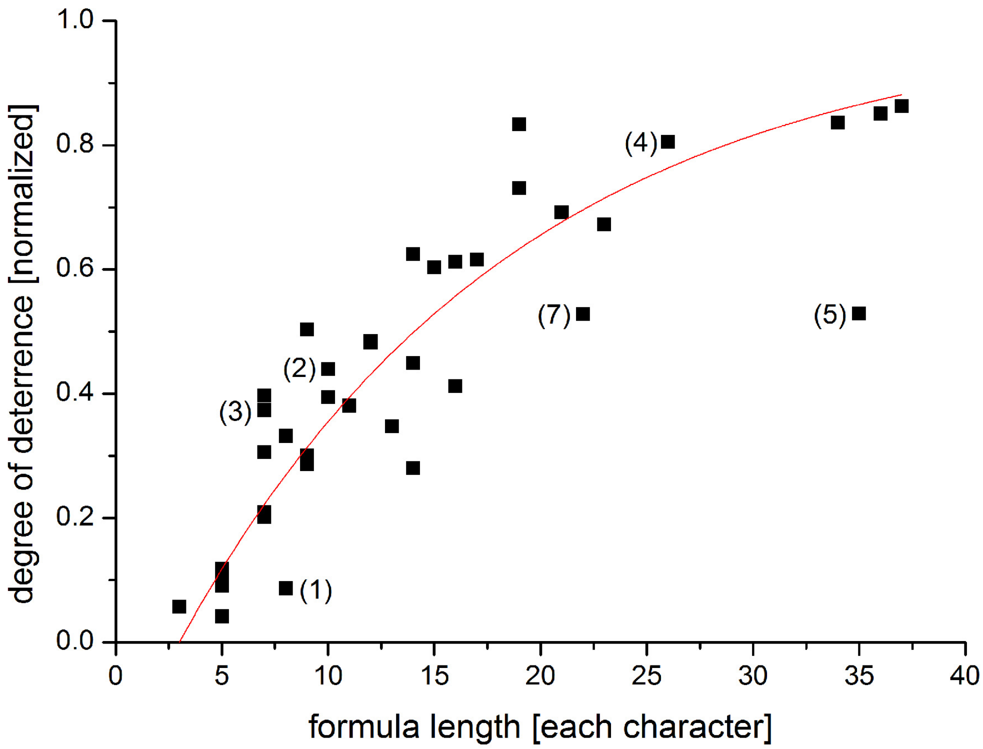


Figure 1: Degree of deterrence vs. formula length for the 38 formulas rated by the students of group 2. The degree of deterrence is defined as the average student rating of the formula within the group, rescaled to the interval $(0, 1)$. The solid line is the best fit curve for the model (6). The labels (1)–(5) and (7) mark the formulas shown in the text

The fit function intersects the abscissa at $x = 3$, reflecting the fact that this is the smallest conceivable length of a formula (e. g. $a = b$). The parameter A determines the slope of the curve and can be interpreted as a saturation length.

The fitting was done for each group separately. The data point marked with (5) was classified as an outlier and excluded from the analysis. We will return to the interpretation of this point below. Without the outlier, the hypothesis that the fit follows a Gaussian distribution is consistent with the data.

The solid line in Figure 1 shows the curve that best fits the data for group 2. Table 1 lists the corresponding value of A together with common measures for the goodness of the fit. It is remarkable, how well the students responses can be modelled with a single free parameter. The standard error of estimate, for example, is about 0.1. It can be interpreted as the average distance of the data points from the fitting curve.

Table 1: Fit parameters and goodness-of-fit measures for the four groups. Note that, unlike for linear models, it is not possible to interpret R^2 as the percentage of the variance explained by the model

	formula				unit			
	A	s	R^2	n	B	S	R^2	n
Student (school)	10.75	0.70	0.76	288	10.69	1.82	0.26	143
subsidiary subject (university)	15.95	1.03	0.78	258	14.96	2.97	0.46	304
teaching physics (university)	16.75	0.99	0.86	24				
physics student (university)	30.42	2.26	0.72	114				

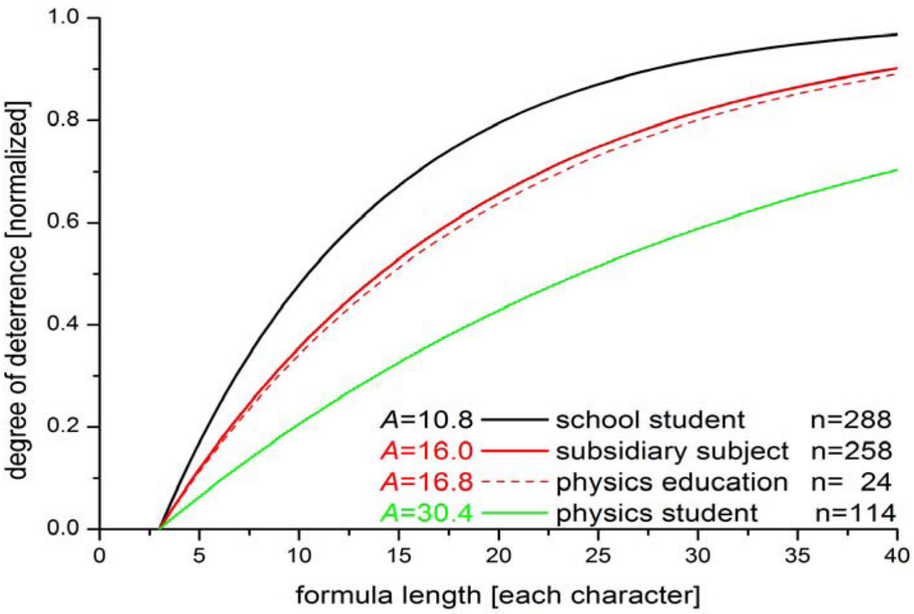


Figure 2: Best fitting curves for the four groups. The characteristic length for each curve can be found in Table 1

Let us finally comment on the rating of Eq. (5). The perceived degree of deterrence is much lower than expected (data point (5) in Figure 1). We believe to see an instance of chunking here. In psychology, chunking designates the ability to group several objects into a larger meaningful units (Chase & Simon, 1973). Eq. (5) consists of several similar terms that can be interpreted as kinetic energies. Because of chunking, the formula may be perceived to consist of "less elements", leading to an apparent reduction of complexity. To a lesser extent, such an effect can also be seen for the formula marked (7)

$$E = \frac{n^2}{8ma^2}(n_x^2 + n_y^2 + n_z^2), \tag{7}$$

where repeating elements may lead to a lower rating. These effects, together with a more detailed analysis of the influence of the other factors mentioned above, are subject to ongoing research.

RESULT — UNIT

A follow-up study has been carried out with physical units (like N·m or V·s/(A·m)). Here we could find similar correlations between the length of a unit and the degree of deterrence (see Figure 3 and Table 2).

Table 2: Different degree of deterrence for the same unit (from 0 to 1)

unit	number of symbols	average degree of deterrence
$\mathrm{T} = \frac{\mathrm{V{\cdot}s}}{\mathrm{m}^2}$	8	0.31
$\mathrm{T} = (\mathrm{V} \cdot \mathrm{s})/\mathrm{m}^2$	10	0.38
$\mathrm{T} = \mathrm{V} \cdot \mathrm{s} \cdot \mathrm{m}^{-2}$	9	0.42

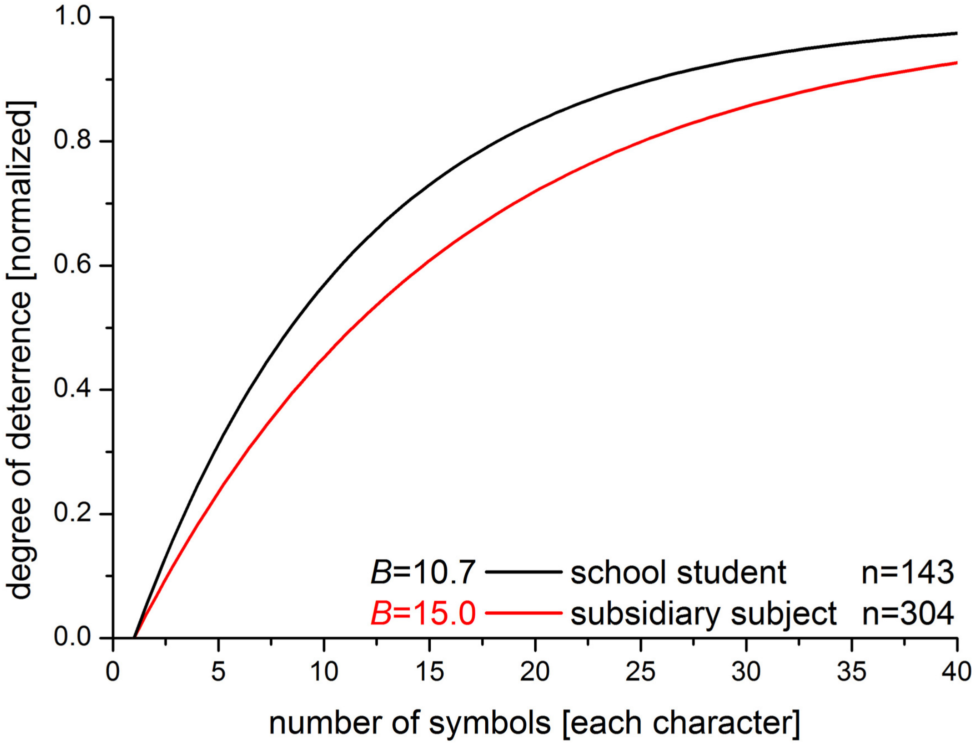


Figure 3: Fitting curve for the deterrence of units

Figure 3 shows the best-fitting curves for a group of school students ($n = 143$) and a group of university students with physics as subsidiary subject ($n = 304$) who assessed the degree of deterrence of 22 units. As in the study on formulas, the length of a unit is determined by the number of its symbols.

The degree of deterrence of units demands a slight modification of the model equation that fitted the data for the length of formulas. The data for units could be fitted to the equation

$$y = 1 - \mathrm{e}^{-\frac{x-1}{B}}. \tag{8}$$

The fit parameter B determines the slope of the curves. As shown in Table 1, it differs for school and university students.

In the study on units, we further obtained some interesting results with regard to different representations of fractions. Table 2 shows three different representations of the same fraction. The first of them is preferred by the students.

Table 2. Different degree of deterrence for the same unit (from 0 to 1)

Further research carried out along these lines (Strahl, Grobe & Müller, 2010) shows that students prefer certain representations of formulas (like a horizontal bar in fractions or writing out the indices within a formula).

REFERENCES

Chase, W. G. & Simon, H. A. (1973). The mind's eye in chess. In Chase, W. G. (Ed.), *Visual information processing*. New York: Academic Press.

Dee-Lucas, D. & Larkin, J. H. (1988). Novice rules for assessing importance in scientific texts. *Journal of Memory and Language*, 27(3), 288–308.

Dee-Lucas, D. & Larkin, J. H. (1991). Equations in Scientific Proofs: Effects on comprehension. *American Educational Research Journal*, 28(3), 661–682.

Hawking, S. A. (1988). *Brief history of time.* New York: Bantam Dell.

Larkin, J. H., McDermott, J., Simon, D. P. & Simon, H. A. (1980). Models of competence in solving physics problems. *Cognitive Science*, 4(4), 317–345.

Larkin, J. H. (1983). The role of problem representations in physics. In Gentner, D. & Stevens, A. L. (Eds.), *Mental models* (75–98). Hillsdale: Erlbaum.

Müller, R. & Heise, E. (2006). Formeln in physikalischen Texten: Einstellung und Textverständnis von Schülerinnen und Schülern. *PhyDid*, 2(5), 62–70.

Strahl, A., Grobe, J. & Müller, R. (2010). Was schreckt bei Formeln ab? — Untersuchung zur Darstellung von Formeln. In *PhyDid B.*

Strahl, A., Mohr, M., Schleusner, U. & Müller, R. (2009). Beurteilung von Formeln durch Schüler – eine Fragebogen-Untersuchung. In D. Höttecke (Ed.), *Chemie- und Physikdidaktik für die Lehramtsausbildung. Gesellschaft für Didaktik der Chemie und Physik. Jahrestagung in Schwäbisch Gmünd 2008.* Münster: Lit-Verlag.

Strahl, A., Mohr, M., Schleusner, U., Krecker, M. & Müller, R. (2010). Akzeptanz von Formeln — Vergleich zweier Erhebungen. In *PhyDid B.*

Alexander Strahl
Rainer Müller
Susan Hagendorf
Julian Grobe
TU Braunschweig, Germany

Scientia in educatione 8(Special Issue), 2017
p. 254–259
ISSN 1804-7106

Informal Teaching of Special Theory of Relativity

Jindřiška Svobodová, Jan Novotný, Jana Jurmanová

Abstract

In the present Case Study we explore the comprehension levels of relativity theory in prospective science teachers who take the introduction to physics lesson at the Faculty of Education. Special Theory of Relativity multimedia animation was used to illustrate basic relativistic consequences. The effect of it for learning was researched. In the research, a case study was used. Research data were obtained by interviews and using open-ended questions prepared by the researcher.

Key words: informal science education, animation, courseware, special relativity.

INTRODUCTION

Nowadays Special Theory of Relativity (STR) is important for our understanding of time, space, matter and energy. It represents an example of creative and analytical thought. Although some of the consequences of the basic ideas may seem intuitive, there are various pitfalls no only for beginners. Many students are looking forward to lessons of STR. They often have high expectations for this topic, but soon they turn that the understanding STR is quite difficult task in practice. Every physicist probably had met with STR insistent critics who claim that STR leads to the absurdities. Physics teacher should be able to vindicate the theory at least for himself (because an effort to convince is usually fruitless). This ability to oppose the critique represents a real touchstone in understanding STR.

When the STR is taught in schools, it is not possible to carry out real experiments. We have prepared several multimedia animations giving a brief overview of relativity as stand alone content files. These short animations were complemented by various questions and problem tasks and were presented to students.

The aim of our study was to find indications and patterns which can help an understanding starting points of the theory of relativity (Geršl et al., 2006).

For research purpose we decided to realize a Case Study focused on student's reading, math, science skills and creative abilities to solve problems. In spite of an increasing availability of animations for science education, there has been little research into the value of animations in science teaching. Stith (2004) has reviewed this issue with a focus on cell biology teaching animations. A review of the literature covering all educational disciplines has indicated that there are certain parameters that need to be considered when making a teaching animation (Tversky & Morrison, 2002).

STR FLASH ANIMATIONS

The textbook "Special Theory of Relativity 2005" is available as downloadable PDF course material for students was prepared several years ago (Geršl et al., 2006; Geršl, Jurmanová & Novotný, 2006). This textbook is still quite popular among physics students and teachers. The carefully structured text and number of explanations make that educational material is suitable for a self-study.

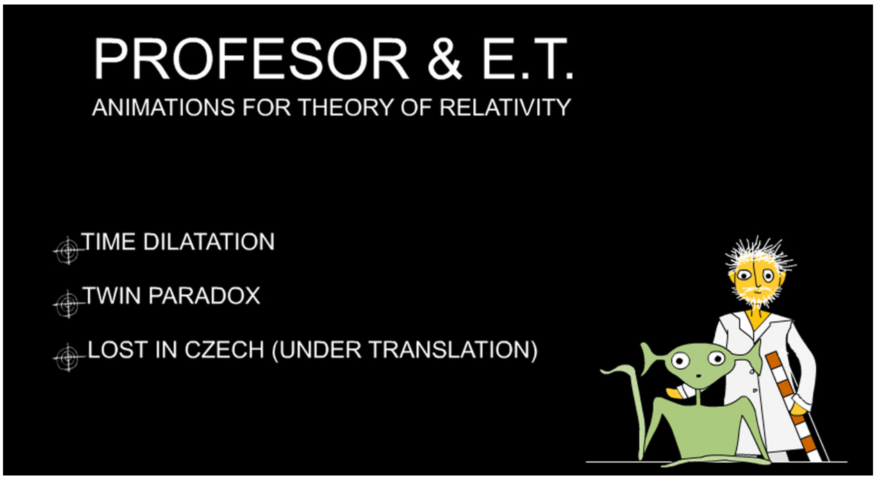
The authors have developed set of cartoon-style multimedia animations illustrated STR. Since this year there is an independent access for animations. We offer free streaming animated files as well as commentary text (this time in Czech only) with a written explanation, all of which explore the STR realm (Svobodová, 2013). The production altogether was simply titled The Cartoon Guide to Relativity.

Every animation is narrative, combining story-telling and visualization. Theory and experiments are appearing on background story. The story begins meeting an Alien (from an advanced civilization that STR applied in everyday practice) and Professor of theoretical physics. Alien traveling at high speed rocket informs Professor of his observations. All measurements and observations of natural phenomena are based on determining the spatial and temporal relations. The main characters Alien and Professor are guides through all manifestations of STR ideas that are away from common sense. The processes in space-time are described from point of view of different frames of reference (we restrict ourselves on inertial systems of reference).

The following thematic sections are available:

- The Basic Science Terms.
- Time Synchronization.
- Adding velocities.
- Time Dilatation.
- Length Contraction.
- Twin Trip.

Much of the material was prepared at level suitable for high school students. This approach is designed for those students who desired better understanding the STR. Students can clarify special relativity terminology in conversation between Alien and a Professor and they can compare their ideas to the processes modeled in animation.



PROFESOR & E.T.
ANIMATIONS FOR THEORY OF RELATIVITY

TIME DILATATION
TWIN PARADOX
LOST IN CZECH (UNDER TRANSLATION)

Figure 1: Internet portal design

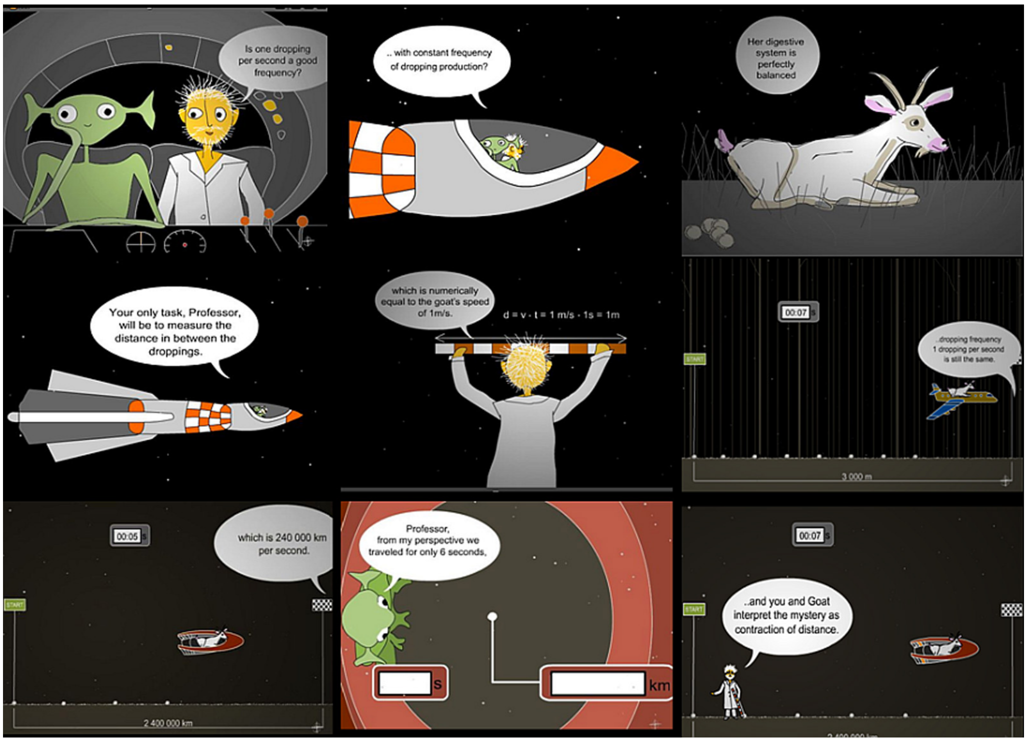
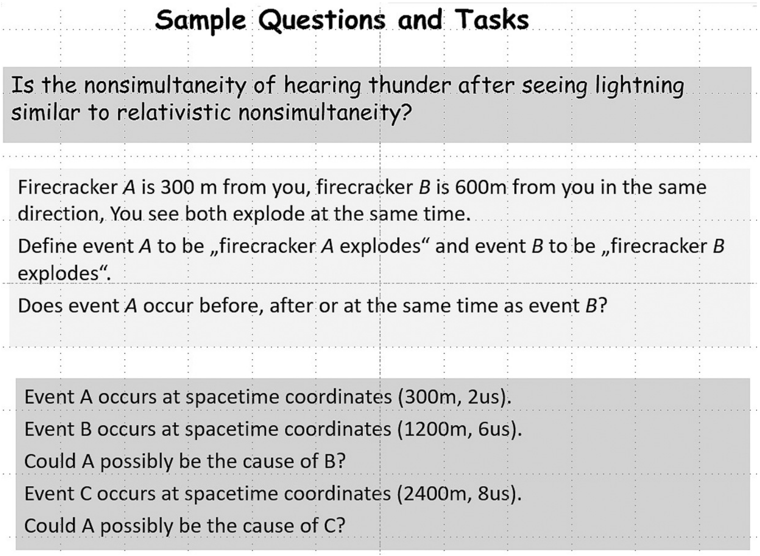


Figure 2: Sample captions of the STR animation

THE RESEARCH DESIGN

The primary goal of our case study was to determine whether the results of students who saw the animation are different from other. We wanted to find out how the observation of animations affects student's approach to perform their solution of requested tasks.

We were looking for factors that could enhance the learning process of STR. From written tests inspired Hewitt (2011), Sherr (2001) we could evaluate student's knowledge and skills and we could identify an incomplete treatment in areas that may prevent from misunderstandings in STR concepts. Test questions were intentionally assigned more generally. Test assignment was designed so that it examined the prerequisites of math, geometry and graphics. Figure 3.



Sample Questions and Tasks

Is the nonsimultaneity of hearing thunder after seeing lightning similar to relativistic nonsimultaneity?

Firecracker *A* is 300 m from you, firecracker *B* is 600m from you in the same direction, You see both explode at the same time.

Define event *A* to be „firecracker *A* explodes“ and event *B* to be „firecracker *B* explodes“.

Does event *A* occur before, after or at the same time as event *B*?

Event A occurs at spacetime coordinates (300m, 2us).

Event B occurs at spacetime coordinates (1200m, 6us).

Could A possibly be the cause of B?

Event C occurs at spacetime coordinates (2400m, 8us).

Could A possibly be the cause of C?

Figure 3: Test questions example

Moreover, we have used the case study research method. The advantage of case study methods is that it provides detail information about a particular case. This helps to set the groundwork for future strong studies. The Case Study is an empirical inquiry allows a rich exploration of student perceptions into common situations.

The research questions we were set: What indicators are changed after student's observation of cartoon animation? Is there a relationship between graphical and geometrical competence and ability to solve the set of tasks? Does the student's ability to clearly formulate their own approach affect the result of test?

THE CASE STUDY METHOD STUDY DESIGN 2013

Participants were university students, mostly future physics teachers. 16 students attending university physics course took part in the study. They fulfilled given test (a set of 15 tasks) in sufficient time.

Students were divided into 2 groups: AA students were shown an animation before their test work, the other group NA only wrote a test without any animation. After that interviews for each student about their worksheets were audio recorded. Records were transcribed and coded. The method of categorization into indicators emerged during the analysis of records. We recombine data to address the initial purpose of the study. In several cases a short interview to gather additional data to verify key observations was necessary.

These observed symptoms and indicators were selected: careful reading, initial acceptance of the task (without any intervention), a clarity in student's explanation, an ability to reformulate task by own words, adequacy of graphic representation, use knowledge of STR, transfer of knowledge and skills from math, geometry and other disciplines, value judgment — a solution based on reasoning, limitation of own approach, creativity, success in task solution, ability to focus and maintain attention.

RESULTS

The outputs are charts and brief descriptions of detected remarkable answers. Several graphs were constructed for comparative analyses. The graph shows (Figure 4) the different distribution of "performance" indicators for the first (AA) and the second (NA) group.

We can see that the most differences are in the categories of knowledge use STR (although most of these tasks and questions don't require knowledge STR) transfer of knowledge from different disciplines and creativity. The length of red arrows (Figure 4) corresponds to increase of the indicator. Shift is in transfer of knowledge from different disciplines and for creativity. The first group shows greater courage to accept tasks and has a better ability to reformulate task in own words. They were more successful in solution tasks.

The comparison of both groups indicates that the influence of fun animations is significant in the majority of items. The most pronounced influence is in indicator transfer of knowledge.

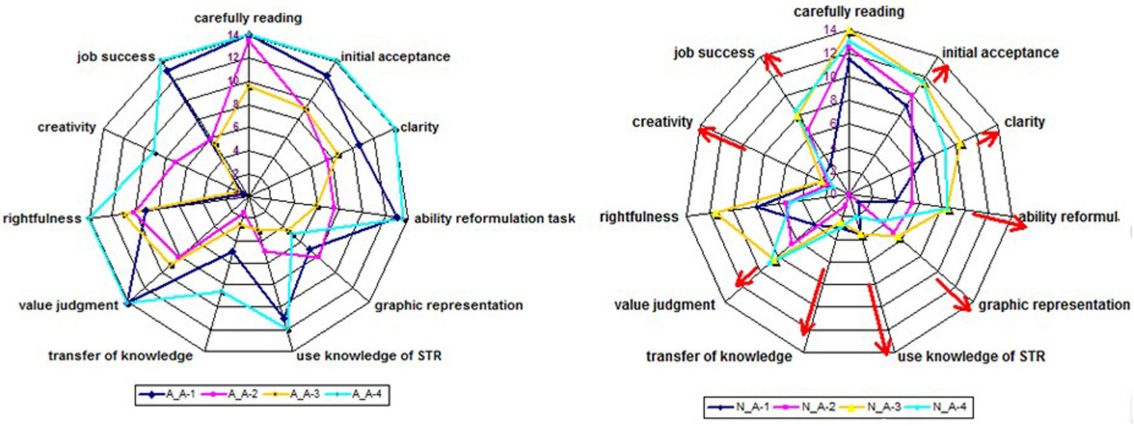


Figure 4: Graphic comparison of both groups

The content analysis of the answers (for example Figure 3) reveals that: students meet difficulties in grasping the relativity of motion and in using the frames of reference properly, several students didn't seem to be able to answer the question about the speed of light.

CONCLUSIONS

The students, who have undertaken STR cartoon multimedia stories, have reported shifts in values our indicators. Students have demonstrated more enthusiasm for the subject matter and they results were better. We can conclude that viewing animation is certainly not a wasting time in the classroom.

The STR Animations website provides the animations as downloadable, reusable, learning objects that teachers can use however they like. In further refinement of improved cartoon animations, authors will work on suggested worksheets and instructor notes.

Next research is now focusing on deeper analysis of the student's concept development when experimenting with STR animation.

ACKNOWLEDGEMENT

Support for this study has been provided by EP project OPVK Moduly jako prostředek inovace v integraci výuky moderní fyziky a chemie reg. č.: CZ.1.07/2.2.00/28.0182.

REFERENCES

Hewitt, P. G. (2011). *Conceptual Physics, 11th edition.* Boston: Addison-Wesley.

Jurmanová, J., Novotný, J. & Geršl, J. (2006). *Úvod do speciální a obecné teorie relativity* [CD-ROM]. České Budějovice: Scientific Pedagogical Publishing.

Novotný, J., Jurmanová, J., Geršl, J. & Svobodová, M. (2006). *Základy teorie relativity.* Brno: Masarykova univerzita.

Novotný, J. & Svobodová, J. (2013). *10th International Conference On Hands on Science, Educating for Science and through Science.*

Sherr, R. E. (2001). *An investigation of student understanding of basic concepts in STR* [Dissertation thesis]. University of Washington.

Svobodová, M. (2013). *STR Cartoon Project Website.* Available at http://www.ped.muni.cz/wphy/C_R/

Stith, B. J. (2004). Use of animation in teaching cell biology. *Cell Biol. Educ.*, 3, 181–188.

Tversky, B. & Morrison, J. B. (2002). Animation: can it facilitate? *Int. J. Hum. Comput. Stud.*, 57, 247–262.

JINDŘIŠKA SVOBODOVÁ
JAN NOVOTNÝ
Faculty of Education, Masaryk University, Brno, Czech Republic

JANA JURMANOVÁ
Faculty of Science, Masaryk University, Brno, Czech Republic

Scientia in educatione 8(Special Issue), 2017
p. 260–267
ISSN 1804-7106

Embedding Formative Assessment and Promoting Active Learning

Elizabeth Swinbank, Mary Whitehouse, Robin Millar

Abstract

In this contribution we outline how the York Science project is using a 'backward design' approach to teaching science to students aged 11–14. We then present some examples of formative assessment tasks and show how simple selected-response questions can be modified to provide teachers with detailed information about students' ideas. Finally we indicate how such tasks can help promote active learning.

Key words: formative assessment, diagnostic questions, backward design.

INTRODUCTION: THE YORK SCIENCE PROJECT

York Science (Millar & Whitehouse, 2012) is a project based in the University of York, UK, which is developing a large package of resources to support the teaching of science to students age 11–14. The project's guiding principles are:

- What matters in science education is what students learn.
- The aim of teaching is to promote learning.
- We need to shift the focus from what is taught to what is learned:
  - from activities to outcomes
  - from the intended curriculum (what teachers teach)
  - to the attained curriculum (what students actually learn)

A key component of the *York Science* resource package is a wide variety of assessment tasks and questions which can be embedded in normal classroom practice and provide evidence of successful learning, or of learning difficulties to which teachers can respond.

The positive impact of formative assessment on student learning has been well established, for example by Paul Black and Dylan Wiliam (1998a, 1998b). John Hattie's synthesis of over 800 meta-analyses (Hattie, 2008) identifies 'feedback' as one of the most effective interventions relating to student achievement. Hattie points out that feedback is most powerful when it is *from the student to the teacher*: "When teachers seek, or are at least open to, feedback from students as to what students know, what they understand, where they make errors, when they have misconceptions — then teaching and learning can be synchronised and powerful." (Hattie, 2008: p. 173).

However, teachers are not always aware of research evidence, and even if they are aware, they might not have the time or resources to reflect fully on its implications or to make appropriate changes to their practice. As Smith and Gorard (2005) showed, even though research indicates the benefits of formative feedback, it may not be implemented effectively.

The *York Science* project is drawing on the research findings to inform the development of resource materials, with the aim of helping science teachers to incorporate effective formative assessment into their teaching.

YORK SCIENCE AND BACKWARD DESIGN

The term *backward design* was used by Wiggins and McTighe (2005) to describe a process of curriculum design that puts the emphasis on student learning outcomes, rather than starting by developing student activities or focusing on the transmission of content.

Backward design is the process adopted by *York Science*. The first step is to decide what it is that we want students to learn — the Learning Intentions. To help us identify these for a chosen area of science, we begin by writing a progression that shows how knowledge and understanding can be built up over time through the development of increasingly sophisticated concepts. We start by listing the most basic ideas and observations that would be introduced to young children and continue some way beyond the level that would usually be reached by a fourteen-year-old student. This is similar in many respects to the approach described by

Wilson (2009). Writing a progression draws on research evidence where available and typically requires several stages of drafting and redrafting.

Once the progression has been written, we identify the part that is appropriate for students in the 11–14 age range. We can then begin to write a framework for the *York Science* topic, starting with a concise narrative summarising the intended learning and a list of what we want students to know and understand — the Learning Intentions.

Next, we consider how we might find out whether the intended learning had taken place — what the Evidence of Learning might be. In order to elicit this evidence, we need to devise tasks and questions, which we call Evidence of Learning Items (ELIs). Only when the Leaning Intentions and ELIs are in place are we, and teachers, in a position to develop learning activities that focus on the Learning Intentions, and whose efficacy can be evaluated using the ELIs.

The process of developing the Learning Intentions and ELIs is iterative (Figure 1). In trying to specify the desired Evidence of Learning it sometimes becomes apparent that the Learning Intention needs to be modified because it is ambiguous, or inappropriate, or assumes some prior learning that we had not previously identified. Similarly, writing ELIs often helps to clarify the Intentions and the Evidence.

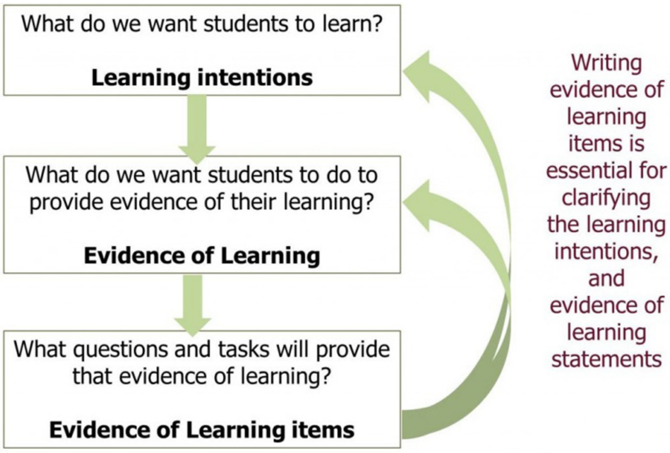


Figure 1: The *York Science* approach

EVIDENCE OF LEARNING ITEMS (ELIS)

The ELIs used by *York Science* include a wide variety of tasks, such as:

- predict the outcome of a practical task, then explain-observe-explain;
- discuss, evaluate and select alternative explanations for an observation;
- make a physical model (e.g. particles in a solid, a liquid and a gas);
- construct a concept map to show relationships between ideas;
- sort and select statements to produce an explanation or argument;
- free writing in response to a question or stimulus.

While many of the ELIs have been devised specifically for *York Science*, some are based on situations used in published assessment schemes such as the Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992), the Children's Learning in Science Project (1980–1989) and EPSE (Millar et al., 2006) projects, and the Assessment of Performance Unit (Black, 1990).

A key feature of many *York Science* ELIs is that they are *diagnostic*. As well as showing the teacher whether a student has learnt what was intended, they provide evidence about how a student might be thinking and the alternative conceptions that they might hold. This feedback is immensely valuable to the teacher, who can then plan the next stage of teaching and learning in order to help the students make progress.

Many ELIs are presented as selected-response questions, as these provide feedback quickly and concisely. This can be done in a pencil-and-paper test, but there are other ways in which a teacher can gather feedback from a class; students can for example be asked to:

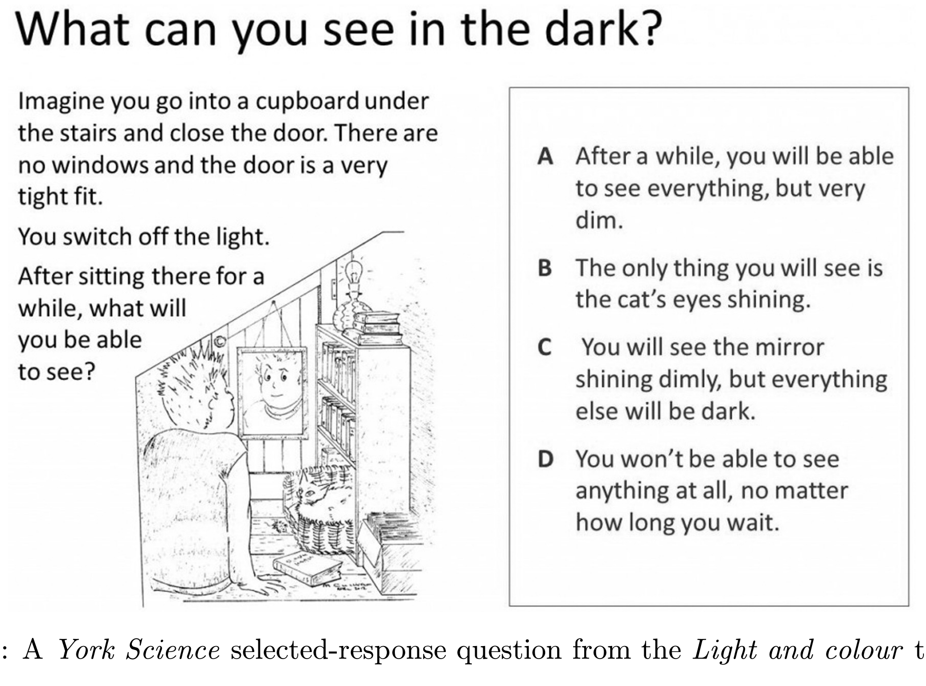
- stand in different areas of the classroom to indicate their chosen response;
- write the letter of their response on a small whiteboard and hold it up;
- use an electronic voting system.

However, a single selected response provides only limited information to the teacher, so the *York Science* team have been exploring ways of 'adding value' to such questions so as to elicit more information. Approaches used by *York Science* include:

- add a free-response question after the students have made their choice, asking them to explain their reasoning;
- add a second part that asks students to choose from some suggested explanations for their first answer.

In the latter case, the suggested explanations draw on research evidence about common misconceptions (for example, the incorrect idea that current diminishes around a simple series circuit, or that motion at constant velocity requires the action of an unbalanced force).

Another approach is to start with a simple multiple-choice question but ask students how sure they are that each response is right or wrong. Figure 2 shows an example. The correct answer is D, but many people would choose one or more of A, B or C. Asking students to use the grid in Figure 3 provides much more information than asking them to select a single response.



What can you see in the dark?

Imagine you go into a cupboard under the stairs and close the door. There are no windows and the door is a very tight fit.

You switch off the light.

After sitting there for a while, what will you be able to see?

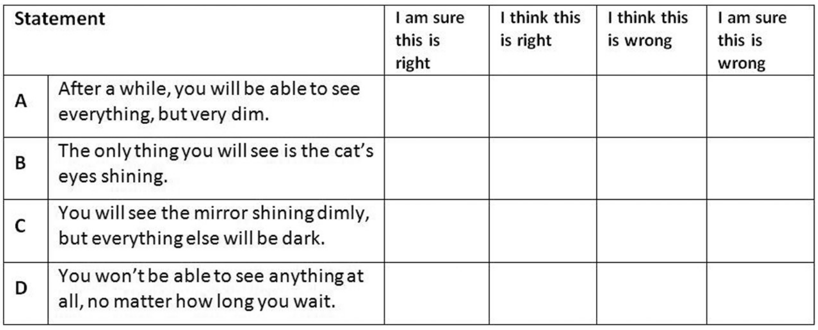
A After a while, you will be able to see everything, but very dim.

B The only thing you will see is the cat's eyes shining.

C You will see the mirror shining dimly, but everything else will be dark.

D You won't be able to see anything at all, no matter how long you wait.

Figure 2: A *York Science* selected-response question from the *Light and colour* topic



Statement		I am sure this is right	I think this is right	I think this is wrong	I am sure this is wrong
A	After a while, you will be able to see everything, but very dim.				
B	The only thing you will see is the cat's eyes shining.				
C	You will see the mirror shining dimly, but everything else will be dark.				
D	You won't be able to see anything at all, no matter how long you wait.				

Figure 3: Answer grid for use with the question in Figure 2

(A cupboard under the stairs seems to be a peculiarly British thing. Delegates at the conference discussed how the question in Figure 2 could be adapted for other nationalities by referring to other completely dark spaces such as a cellar, a bathroom without windows, an underground cave or a remote, unlit, rural location on a cloudy night.)

Another way to gather information about students' thinking is to allocate each student 100 points and ask them to distribute them between answers A, B, C and D. Tell them that they will score all the points that they give to the correct answer (or answers). For example, a student who is very confident might give 100 points to a single response, whereas someone who is undecided between two responses might give 50 points to each one.

Figure 4 shows another variation on the selected-response question. This item presents a sequence of choices and the selected responses build up an explanation, so the ELI tests understanding of the whole 'story' of how we see.

USING ELIs

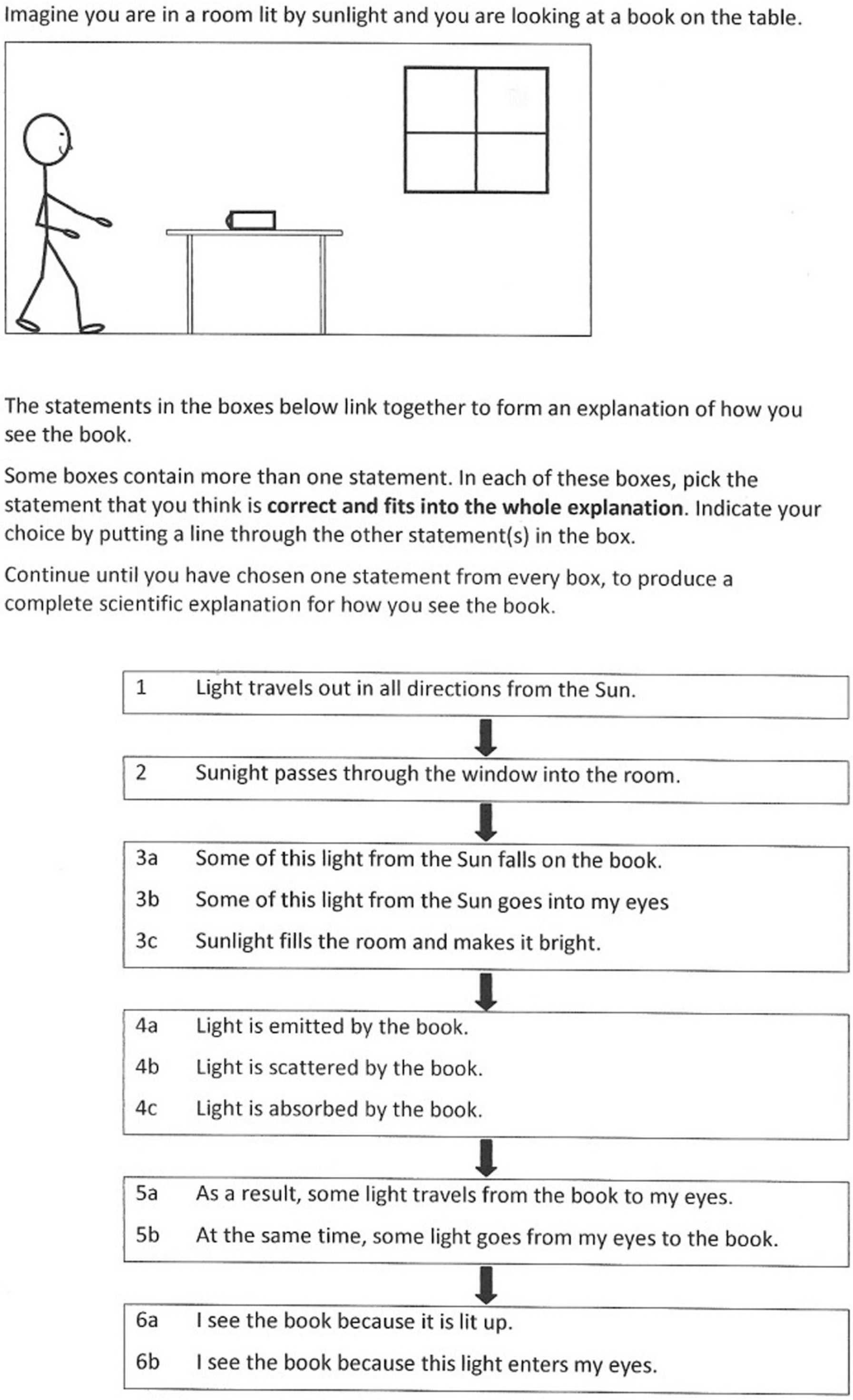
The *York Science* project is encouraging teachers to use ELIs in a wide variety of ways, with regard to both *when* they are used and *how* they are used.

ELIs can be used:

- at the start of a lesson, or sequence of lessons, to assess students' prior knowledge and understanding;
- part way through a lesson, or sequence of lessons, to assess progress and to help the teacher plan what to do next;
- at the end of a topic, for summative assessment and to gauge the overall effectiveness of the teaching and learning.

While ELIs can be used by individual students to inform a teacher about their own learning, there are many more productive ways to use them with a class. Here are just a few of the ways that *York Science* teachers have used ELIs:

- Project the ELI onto a whiteboard. Ask students to indicate, by raising their hands, what they think is the correct response.
- Give the same ELI to each small group of 2–4 students. Ask them to discuss and decide what they think the answer should be. Tell them that each student should be able to explain their group's answer to the rest of the class.
- Instead of telling students the right answer, follow the ELI with a practical activity so that they can find out the answer for themselves.



Imagine you are in a room lit by sunlight and you are looking at a book on the table.

The statements in the boxes below link together to form an explanation of how you see the book.

Some boxes contain more than one statement. In each of these boxes, pick the statement that you think is **correct and fits into the whole explanation**. Indicate your choice by putting a line through the other statement(s) in the box.

Continue until you have chosen one statement from every box, to produce a complete scientific explanation for how you see the book.

1 Light travels out in all directions from the Sun.

2 Sunight passes through the window into the room.

3a Some of this light from the Sun falls on the book.
3b Some of this light from the Sun goes into my eyes
3c Sunlight fills the room and makes it bright.

4a Light is emitted by the book.
4b Light is scattered by the book.
4c Light is absorbed by the book.

5a As a result, some light travels from the book to my eyes.
5b At the same time, some light goes from my eyes to the book.

6a I see the book because it is lit up.
6b I see the book because this light enters my eyes.

Figure 4: Constructing an explanation

- Display an answer grid (Figure 3) on a large flipchart or on a whiteboard. Give each student some Post-it stickers and ask them to place a sticker in their chosen cell for each response. After discussion and teaching, which might include practical work and demonstration, repeat the process.

As these suggestions illustrate, ELIs can lead naturally to active learning, where students are involved in discussing and refining their ideas, and in hands-on exploration. So, while the backward design approach focuses initially on outcomes and assessment, there is no clear dividing line between formative assessment and learning, and a task designed for assessment can be used as the starting point for actively engaging students in exploration of scientific concepts and principles.

Teachers are responding very positively to *York Science* and are seeing the benefits to their teaching, like this teacher who remarked "The materials have caused me to reconsider my approach to lesson planning, and have been an excellent aid."

It is particularly pleasing that teachers are using the *York Science* materials as a model for devising their own ELIs then sharing their ideas with the *York Science* project team and with other teachers. This is a comment from the teacher who thought of using Post-it stickers for 'What can you see in the dark?' (Figures 2 and 3) and went on to write her own similar ELIs for other topics:

"The students enjoyed the hubbub of getting four (what, miss, four EACH?) post-it notes and sticking them to the part of the board that represented their answer. A benefit of doing it like this is that you can get the class to stick up their responses, teach the lesson, then ask if they would like to change their answers making the process more of a demonstration of their progress and less of a snapshot of their misconceptions. Thank you twitter and York Science, I can see this idea being adapted for many, many lessons!"

Conclusion

So far, *York Science* Learning Intentions and ELIs have been drafted for six topics — two for each of physics, chemistry and biology (the physics topics addressed to date are *Light and Colour* and *Electric Circuits*). Each ELI is accompanied by notes for teachers which include a summary of relevant research evidence, for example highlighting common misconceptions.

More information about the project and samples of these materials are available from the 'Resources' pages of the *York Science* website. You can also subscribe to the *York Science* blog and follow us on Twitter to hear about new posts and updates. The aim is eventually to produce Learning Intentions and ELIs for all science topics commonly taught in the UK to students aged 11–14.

References

Black, P. (1990). *APU* Science: The past and the future. *School Science Review*, 72(258), 13–28.

Black, P. & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice*, 5(1), 7–74.

Black, P. & Wiliam, D. (1998).*Inside the black box: Assessment for learning in the classroom.* London: Kings College London.

Children's Learning in Science Project (1980–1989). *Resource archive.* York: National STEM Centre. Available at
http://www.nationalstemcentre.org.uk/elibrary/collection/464/children-s-learning-in-science-project

Hattie, J. (2008). *Visible Learning: A synthesis of over 800 meta-analyses relating to achievement.* London: Routledge.

Hestenes, D., Wells, M. & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, 30, 141–157.

Millar, R., Leach, J., Osborne, J. & Ratcliffe, M. (2006). *Improving subject teaching. Lessons from research in science education* (Chapters 3 and 6). London: Routledge.

Millar, R. & Whitehouse, M. (2012). The York Science Project — embedding assessment for learning. *Education in Science (EiSXtra)*, 1–3. Available at
http://yorkscience.org.uk/wp-content/uploads/2013/03/1211-YS-in-EiSxtra1.pdf

Smith, E. & Gorard, S. (2005). 'They don't give us our marks': The role of formative feedback in student progress.*Assessment in Education: Principles, Policy & Practice*, 12(1), 21–38.

The *York Science* project website:
http://www.york.ac.uk/education/projects/yorkscience/

Wiggins, G. P. & McTighe, J. (2005). *Understanding by Design.* Alexandria, VA: ASCD.

Wilson, M. (2009). Measuring progressions: Assessment structures underlying a learning progression. *Journal of Research in Science Teaching*, 46(6), 716–730.

Elizabeth Swinbank
Mary Whitehouse
Robin Millar
University of York, UK

Scientia in educatione 8(Special Issue), 2017
p. 268–275
ISSN 1804-7106

Learn from History: Lessons from Early Modern Japanese Physics Experiment Textbooks

Hiroshi Takahashi, Akira Akabane, Jun Shozawa, Toyomi Tamaki

Abstract

The aim of our study is to explore the early history of the education of physics experiments in the Meiji era of Japan (1868–1912). In this paper, we examine three Japanese physics experiment textbooks which were published during 1880s. One characteristic feature is that the most of the experiments could be performed using simple handmade apparatuses. We consider what can be learned from the ingenuity of physics education pioneers of the late 19th century.

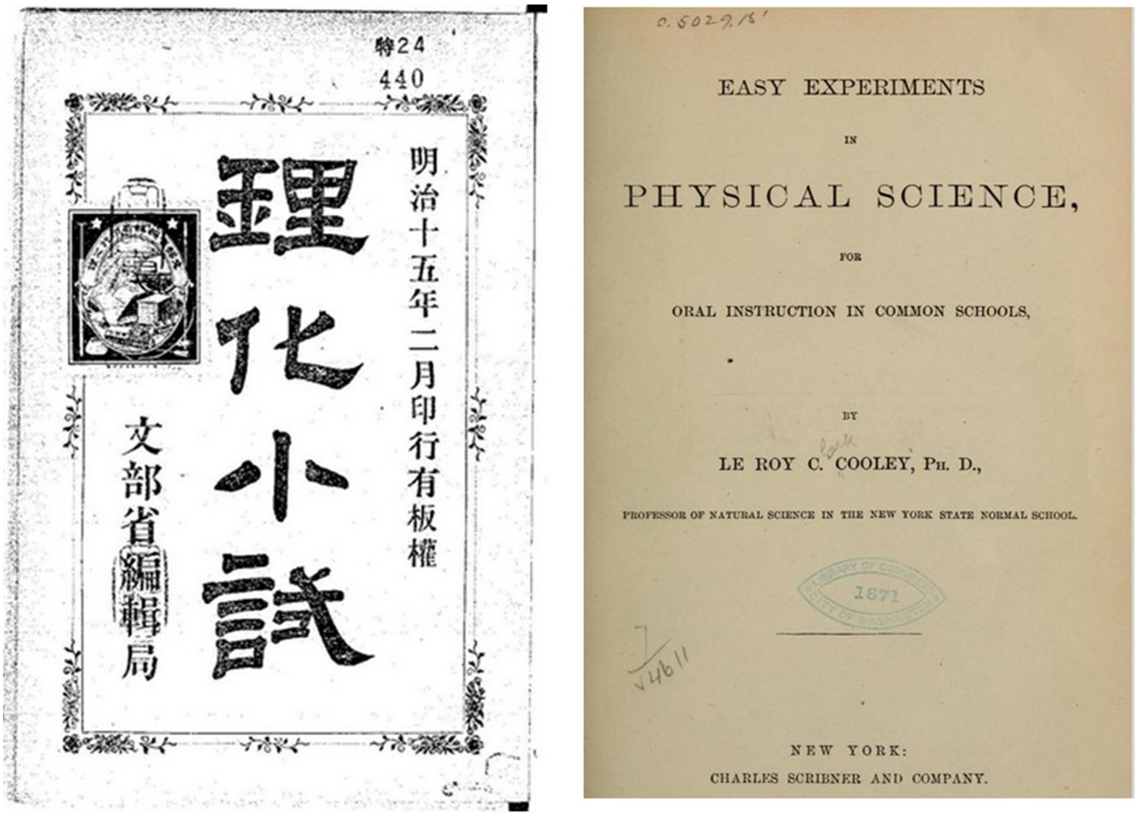
Key words: physics experiment, Meiji era, handmade, simple experiment, history of physics education.

INTRODUCTION

The island nation of Japan had adhered to a closed-door policy to the outside world between 1639 and 1854. During this period, Japan traded only with China and the Dutch through restricted ports. As a result, very little knowledge of modern Western science reached Japan by means of Chinese and Dutch books. From the inception of the Meiji Restoration in 1868, leaders of the nascent Meiji government recognized that science and technology were essential to the development of new industry. Consequently, the full-scale influx of modern Western science was encouraged. The general public also felt that, learning rational thinking of the West would be required for the country's modernization. It is within this context that a publication boom of physics textbooks occurred and present-days historians refer to it as *kyuri-netsu* (literally, enthusiasm for physics) (The Physical Society of Japan, 1978). Itakura (2009) reported that *ca.* 40 general science books that primarily cover physics were published in 1872–1873. One of the leading educational figures of his time, Yukichi Fukuzawa (1835–1901), eagerly disseminated the new idea of rational thinking. His work, *Kunmo Kyuri Zukai* (Illustrated Introductory Physics) (Fukuzawa, 1868), first published in 1868, is regarded as the trigger of the publication boom in the early Meiji era.

The Japanese school educational system modelled after the West began when the Education System Order (*Gakusei*) was promulgated in August, 1872. The elementary school curriculum was regulated according to the Elementary School Curriculum (*Shogaku Kyosoku*) established in the following month, and in which five subjects related to science appeared, i.e., Regimen, Natural Philosophy, Natural History, Chemistry, and Physiology (*yojo-kujo*, *kyurigaku-rinko*, *hakubutsu*, *kagaku*, and *seiri*, respectively). The entire curriculum was expected to be completed in eight years. The main scientific subjects, natural history, chemistry, and physiology were taught on the seventh and eighth grades. In practice, however, as Itakura (2009) revealed, the majority Japanese elementary schools of the 1870s, there were actually relatively few students in the higher grades where science was taught. After 1880, the number of students there began to increase and as a result, science education at the elementary level began in earnest. This situation brought about an earnest discussion on how to best perform physics experiments in the classroom. Domestic leaders of science education had recognized the importance of performing experiments and consequently, no less than ten physics experiment textbooks in Japanese were published successively during the four-year span of 1882–1886, as Nagata (1994) has shown.

In order to explore the early history of physics experiments education in Meiji-era Japan, here, we analyze several representative textbooks among these textbooks. In particular, we will deal with three textbooks. The first is *Rika-Shoshi* (Simple and Easy Experiments of Physics and Chemistry) (1882), a translation of an American textbook but notable for being the first physics experiment textbook written in Japanese. The second is *Kan'i-Shiken-Ho* (Simple Experiments) (Udagawa, 1885) written by Jun'ichi Udagawa (1848–1913). The latter textbook is not a translation, but rather the first original Japanese physics experiment manual. The third textbook is *Kan'i Kikai Rikagaku Shiken-Ho* (Physics and Chemistry Experiments using Simple Apparatuses) (Goto & Miyake, 1886), written by Makita Goto (1853–1930), who is recognized as the most influential figure of Meiji-era physics education. Udagawa is considered a leader of the first generation of educators in physics, and Goto is a leader of the second generation. The outstanding feature of these three text-



明治十五年二月印行有板權

理化小試

文部省編輯局

EASY EXPERIMENTS
IN
PHYSICAL SCIENCE,
FOR
ORAL INSTRUCTION IN COMMON SCHOOLS,

BY
LE ROY C. COOLEY, PH. D.,
PROFESSOR OF NATURAL SCIENCE IN THE NEW YORK STATE NORMAL SCHOOL.

NEW YORK:
CHARLES SCRIBNER AND COMPANY.

a) b)

Figure 1: a) The title page of *Rika-Shoshi* (1882), b) The title page of *Easy Experiments in Physical Science* by Le Roy C. Cooley (1870)

books is that the most of experiments can be performed with low-cost, everyday materials.

First Japanese Physics Experiment Textbook, *Rika-Shoshi*

The first Japanese textbook on physics laboratory teaching is *Rika-Shoshi* (Figure 1a)) that was published by *Monbusho* (the Ministry of Education) in 1882. This textbook was translation of *Easy Experiments in Physical Science* (Figure 1b)) by Le Roy C. Cooley (1833–1916) and published in 1870 by Charles Scribner and Company of New York. The translator of the textbook, Ten Maomura (1853–?), worked at the Tokyo Educational Museum (present-day Tokyo National Museum) when the textbook was published. The original Japanese is the same as the original, which contains 178 experiments, of which 145 are for physics and the remaining 33 for chemistry. As mentioned above, the experiments could be performed by using low-cost apparatus or everyday materials.

Needless to say, during Meiji ear, there were vast differences in lifestyle and culture between the East and West. Thus, for Japanese to obtain the same materials was extremely difficult. Consequently, the Japanese version, *Rika-Shoshi*, contains some explanatory notes. For example, the explanatory note in *Rika-Shoshi* recommend using *beniko*, a fine Japanese red powder used in make-up, for coloration as a substitute for of cochineal extract powder. In addition, other explanatory notes called for modifications to the experiments themselves (see Takahashi et al., 2014 for details).

As we have covered the personal history of Jun'ichi Udagawa (1848–1913), the editor of *Rika-Shoshi* elsewhere (Takahashi et al., 2014), we would like to turn to Le Roy C. Cooley (1833–1916), as described in *An Historical Sketch of the State Normal College at Albany* (New York State University, 1894). A graduate of Union College in 1858, Cooley taught mathematics at the Fairfield Academy and Cooperstown Seminar. From 1861, he was appointed professor of Natural Science at the New York State Normal College in Albany. In 1874, he moved to Vassar College, one of oldest colleges for women in the United States. There, he became the first professor of physics, his Ph.D. having been conferred by Union University four years earlier.

One of his most notable review papers was *The Molecular Theory* published in *Popular Science Monthly* (Volume 15, August 1879) (Cooley, 1879). An anonymous reviewer (*Book review*, 1880) of Cooley's *The New Text-Book of Physics* (1880) wrote, "Professor Cooley was among the first to attempt to introduce into elementary instruction in physics the modern doctrine of molecules and molecular action". In fact, *Easy Experiments in Physical Science* was written consistently on the basis of molecular theory. Itakura published a reproduction of *Rika-Shoshi* in 1972. In his postscript of the reproduction, Itakura (1972) wrote, "reading *Rika-Shoshi* makes me overjoyed because I found that that early Meiji-era scientific concepts are based on the modern view of matter supported by molecular theory." Itakura have insisted that molecular theory should be taught even at elementary school levels (Itakura, 2009). Indeed, it is probable that *Rika-Shoshi* played an essential role in spreading the concept of molecular theory in Meiji-era Japan.

As expected from the full title of *Easy Experiments in Physical Science, for oral instruction in common schools*, the textbook is not only a teaching manual of physics experiments but also an instructs teachers how to adequately pose questions to students during the experiments. In fact, Cooley wrote "While making an experiment the teacher ought, by skilful questions and appropriate remarks, to keep the attention of the children upon it, so that every part of the apparatus shall be observed and every action definitely seen. Above all things ought to care to be taken that the final inference is seen to be the natural consequence of the facts observed in the experiments."

First Japanese Original Physics Experiment Textbook, *Kan'i-Shiken-Ho*

The editor of *Rika-Shoshi* textbook was Jun'ichi Udagawa, a physics teacher of the Gunma Normal School (now, Gunma University). According to university archives, Udagawa performed some experiments with handmade apparatuses in his physics lectures of 1884. He published the first Japanese original physics experiment textbook, *Kan'i-Shiken-Ho* (Simple Experiments) at the following years. In it, Udagawa explained how experiments in his previously published textbook, *Butsuri-Shoshi* (Short Course of Physics) could be performed by using mainly everyday materials: "When we have no flask, we should use an ordinal bottle of false bottom", or, "when no magnetic needle is available, the use of a sewing needle is recommended". A sewing needle can be easily magnetized by rubbing it with a magnet. When the magnetized sewing needle is rotated freely by suspending it with a thin silk thread, the needle will rotate to the direction of north-south axis.

Physics had become established in the school curriculum at that time. In the preface of *Kan'i-Shiken-Ho*, Udagawa describes his motive for authoring the textbook: “Physics is an indispensable subject in the elementary school curriculum, as evident by the recent *Guidelines for the Course of Study for Elementary Schools* (Shogaku Kyosoku Koryo, 1881), thus, I published *Butsuri-Shoshi* (Short Course of Physics).” But Udagawa fully realized the limitations of Japanese schools at that time, saying, “Because physics is based on substance, the laws and principles of physics should be explained through physical experiments. However, local governments are severe financial straits, e.g., and in most mountain villages, it is extremely difficult to obtain satisfactory experimental instruments. Therefore, I wrote this textbook.” Although the Gunma Normal School had proper equipment to perform demonstration experiments at that time (Takahashi et al., 2014). Udagawa preferred to use handmade instruments in his classes. We can interpret such actions that Udagawa thought that when his students became teachers and were placed at a poor rural school, they could make do with common everyday materials.

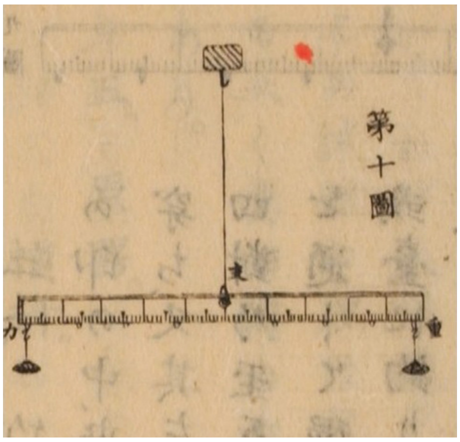


Figure 2: Balance made from a Bamboo Scale

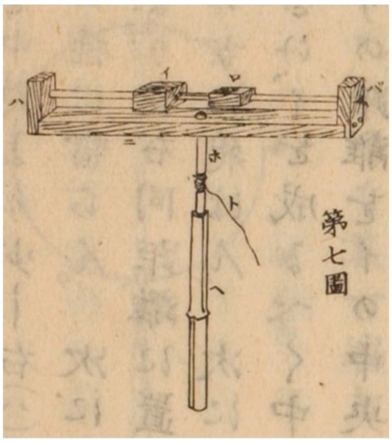


Figure 3: Bamboo apparatus for showing centrifugal force

Makita Goto and His Simple Experiment Textbook

If Jun'ichi Udagawa belonged to the first generation of Japanese physics educators, Makita Goto was a leader in the second generation. Udagawa resigned from the Gunma Normal school in 1885. He then went to work at Imperial Japanese Army General Staff Office, where he taught surveying and photographic techniques for cartography (Sugiyama, 1911). Udagawa never returned to teach physics at school and he disappeared from the world of physics education after his resignation from the Gunma Normal School. In Udagawa's footsteps, Makita Goto became a leader of physics education. Five years younger than Udagawa, Goto taught physics at the Tokyo Normal School (now Tsukuba University) from 1877 to 1914. During his tenure, he had taught the next generation of Japanese physics teachers.

Goto authored a large number of physics textbooks, usually co-authored with his disciples. Goto's first experiment textbook, *Kan'i Kikai Rikagaku Shiken-Ho Kan-*

Ichi (*Simple Physics and Chemistry Experiments Using Homemade Apparatuses, No. 1*) was co-authored by Yonekichi Miyake (1860–1929), and published in 1885. The title of "No. 1" would seem to indicate a series but no subsequent publication appeared. Although the title indicates that chemistry experiments are included, most of the experiments of the textbook are in physics. It could be that the next book in the series would describe mainly chemistry experiments.

Although not exclusive to *Kan'i Kikai Rikagaku Shiken-Ho Kan-Ichi*, typical of Goto's work is that many of the experimental apparatuses are made from wood or bamboo. Figure 2 shows a balance made from a bamboo scale. To explain centrifugal force, Goto devised an apparatus (shown in Figure 3) that when rotated, two wooden pieces, supported by thin metal wires but are freely movable, move to both ends due to centrifugal force. Many physics textbooks published in Europe and America in the late 19th century, explain the mechanism of lifting-Pump using an illustration as in Figure 4. The lifting-Pump which appears in *Kan'i Kikai Rikagaku Shiken-Ho Kan-Ichi* is made from bamboo tubes (Figure 5).

Most of the architecture in Europe and North America employs inorganic materials such as stones and bricks. In contrast, traditional Japanese architectures such as Buddhist temples, Shinto shrines, are made mainly of wood. It is only natural then, that Japanese physics textbooks would employ traditional building materials such as those found in Goto's work.

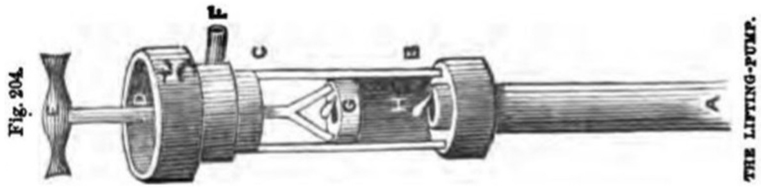


Figure 4: Lifting-pump. This figure is taken from *A Natural Philosophy* by G. P. Quackenbos (1869)

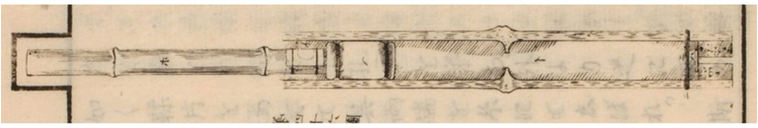


Figure 5: Balance made from a Bamboo

Conclusions

Under the Elementary School Curriculum (*Shogaku Kyosoku*) of 1872, Japanese educational authorities insisted that experiment be performed in science lessons (Nagata, 2003). However, the central government did not usually bear the cost of elementary and secondary schools, rather but the local villages, towns, and prefectures did. Of course, the financial health of local governments varied widely and it certainly was quite difficult for many schools to obtain a full set of ready-made experimental instruments. Given these circumstance, it would be entirely appropriate for the Ministry of Education to publish a translation of *Easy Experiments in Physical Science* as the first physics experiment textbook for elementary schools. The majority of its experiments can be performed using low-cost everyday materials. In spite of the vast differences in culture and lifestyle, because they had a good understanding of handmade physics experiments developed in Europe or North America, early modern Japanese physics educators successfully modified the same experiments with a dash of local ingenuity, especially traditional wood-working.

So, what can be learned from this discussion of early physics experiment textbook in the late 19th century? The same would apply today if one were to use teaching materials developed by other people in a different context. The most important thing is not to get funding and introduce only the newest and latest teaching materials. It is imperative for educators to consider which improvements or adaptations are required to optimize the materials for their own context. There is no denying that some money is necessary to prepare an experimental apparatus and virtual experiments simulated on a computer can reduce expenses. We would so well to bear in mind Udagawa's preface to *Kan'i-Shiken-Ho*, "physics is based on substance". and that touching and operating real substances are indispensable to understanding the physical world. Handmade and inexpensive experimental apparatuses similar to those developed in the late 19th century could be used in present-day classrooms, if one were to add the appropriate modifications.

ACKNOWLEDGEMENT

We would like to acknowledge and thank the staff of the Gunma University Library for their effort in preserving the archives. We would also like to thank Professor Barry Keith (Gunma University) for his English revision of the manuscript. This work was supported by JSPS KAKENHI Grant Numbers 25282043 and 19500779.

REFERENCES

Book review. (1880). *The Popular Science Monthly*, 18(11), 135–136. Available at http://archive.org/details/popularsciencemo18newy

Cooley, L. C. (1870). *Easy experiments in physical science, for oral instruction in common schools.* C. Scribner and Company. Available at http://archive.org/details/easyexperiments00cool

Cooley, L. C. (1879). The molecular theory. *The Popular Science Monthly*, 15(8), 462–470. Available at http://archive.org/details/popularsciencemo15newy

Cooley, L. C. (1880). *The new text-book of physics.* New York: Charles Scribner's Sons. Available at http://archive.org/details/newtextbookofphy00coolrich

Fukuzawa, Y. (1868). *Kunmo Kyuri Zukai (Illustrated introductory physics).* Keio-Gijuku. Available at http://kindai.ndl.go.jp/info:ndljp/pid/830074

Goto, M. & Miyake, Y. (1886). *Kan'i Kikai Rikagaku Shiken-Ho Kan-Ichi (Simple physics and chemistry experiments using homemade apparatuses, No. 1).* Fukyu-Sha.

Itakura, K. (1972). *Postscript in the reproduction of Rika-Shoshi.* Kasetsu-Sha.

Itakura, K. (2009). *Zoho Nihon Rika Kyoiku-Shi (Japanese history of science education, revised and enlarged edition).* Kasetsu-Sha.

Nagata, A. (1994). *Nihon Rika Kyouzai-Shi (The history of Japanese general science teaching materials).* Tokyo Horei Publishing.

Nagata, A. (2003). *Shi-Rika-Kyoiku-Nyumon (New introduction on general science education).* Hoshi-No-Wano-Kai.

New York State University, Albany. (1894). *An historical sketch of the State Normal College at Albany, N.Y. and a history of its graduates for fifty years, 1844–1894.* Albany: Brandow Print Company. Available at http://archive.org/details/historicalsketch01newy

Sugiyama, K. (1911). Okayama-Ken-Meikan (The Directory of Okayama Prefecture).

The Physical Society of Japan. (1978). *Nihon No Butsurigaku-Shi (Japanese history of physics).* Tokai University Press.

Quackenbos, G. P. (1869). *A natural philosophy.* New York: D. Appleton and Company. Available at http://archive.org/details/anaturalphiloso06quacgoog

Rika-Shoshi (Simple and easy experiments of physics and chemistry). (1882). Monbusho. Available at http://kindai.ndl.go.jp/info:ndljp/pid/826131

Takahashi, H., Akabane, A., Shozawa, J. & Tamaki, T. (2014). Rika-Shoshi, the first physics experiment textbook published in Japanese and its editor, Jun'ichi Udagawa. JPS Conf. Proc. 1, 017023 . Available at http://journals.jps.jp/doi/abs/10.7566/JPSCP.1.017023

Udagawa, J. (1885). *Kan'i-Shiken-Ho (Simple experiments).* Bungaku-Sha. Available at http://kindai.ndl.go.jp/info:ndljp/pid/830422

HIROSHI TAKAHASHI
Faculty of Science and Technology, Gunma University, Maebashi, Japan

AKIRA AKABANE
Saitama Medical University, Saitama, Japan

JUN SHOZAWA
Tokyo Future University, Tokyo, Japan

TOYOMI TAMAKI
Mathematical Assist Design Laboratory, Maebashi, Japan

Scientia in educatione 8(Special Issue), 2017
p. 276–284
ISSN 1804-7106

Transforming the Learning Environment of Undergraduate Physics Laboratories to Enhance Physics Inquiry Processes

Gregory P. Thomas, Al Meldrum, John Beamish

Abstract

Concerns persist regarding the lack of promotion of students' scientific inquiry processes in undergraduate physics laboratories. The consensus in the literature is that, especially in the early years of undergraduate physics programs, students' laboratory work is characterized by recipe type, step-by-step instructions for activities where the aim is often confirmation of an already well-established physics principle or concept. In response to evidence reflecting these concerns at their university, the authors successfully secured funding for this study. A mixed-method design was employed. In the 2011/2012 academic year baseline data were collected. A quantitative survey, the Undergraduate Physics Laboratory Learning Environment Scale (UPLLES) was developed, validated, and used to explore students' perceptions of their physics laboratory environments. Analysis of data from the UPLLES and from interviews confirmed the concerns evident in the literature and in a previous evaluation of laboratories undertaken in 2002. To address these concerns the activities that students were to perform in the laboratory section of the course/s were re/designed to engage students in more inquiry oriented thinking and activity. In Fall 2012, the newly developed laboratory activities and tutorials, were implemented for the first time in PHYS124; a first year course. These changes were accompanied by structured training of teaching assistants and changes to the structure of the evaluation of students' laboratory performance. At the end of that term the UPLLES was administered ($n = 266$) and interviews with students conducted ($n = 16$) to explore their perceptions of their laboratory environments. Statistically significant differences ($p < .001$) between the students in the PHYS 124 classes of 2011/2012 and 2012/2013 across all dimensions were found. Effect sizes of 0.82 to 1.3, between the views of students in the first semester physics classes of 2011/2012 and 2012/2013, were also calculated suggesting positive changes in the laboratory inquiry orientation. In their interviews, students confirmed and detailed these positive changes while still noting areas for future improvement.

Key words: undergraduate physics education, inquiry, laboratory learning environments.

INTRODUCTION: THE PROBLEM FACING US AT THE UNIVERSITY OF ALBERTA

Undergraduate science laboratories are major teaching components within university science faculties worldwide. In the Department of Physics at the University of Alberta the annual budget for undergraduate laboratories is approximately \$1.6M for teaching assistants' (TAs) and staff salaries, and space is allocated within the new Centennial Centre for Interdisciplinary Science with a capital cost of over \$13M. Equipment maintenance adds around \$50 000 per annum. Annually, over 2 000 undergraduate students pass through these laboratories. The cost, effort, and time involved are considerable. Obviously, laboratories are a key element of the undergraduate physics learning experience at the University of Alberta. This situation is the same at many universities, worldwide.

However, despite their importance, the quality and extent of student inquiry in first-year undergraduate Physics laboratories is a long-standing issue across universities in Canada and internationally. This, in part, is due to diverse opinions regarding the purpose/s of such activities, ranging from the development of critical thinking skills to equipment manipulation. Key objectives reportedly range from 'developing critical thinking skills' to 'glassware manipulation' (Weaver et al., 2008). Many students believe the primary objective of labs is to "reinforce the lecture material" (Russell et al., 2008), developing a 'confirmation' expectation through their high school experiences (Weaver et al., 2008). Recipe-like laboratory formats persist as the dominant element of instructional design, but these formats do not adequately support the development of students' inquiry processes. To determine the objective of labs, the National Research Council commissioned a detailed investigation (National Academy of Sciences, 1996), asking what the primary motivation of the undergraduate laboratory should be. Contrary to most traditional views, it is increasingly acknowledged that *'science as inquiry'* should pedagogically guide laboratory-based instruction (National Academy of Sciences, 1996), and that labs should engage students in thinking processes and activities similar to practicing scientists (National Research Council, 2000).

At high-school and undergraduate levels, many teachers and students believe, that science advances linearly, following the 'hypothesis-testing model' (Windschitl, 2002). In classrooms this is called *the scientific method*. This view is an inadequate representation of scientific inquiry and reasoning. Many scientific advances have been made without following this so-called method. Sometimes scientists have no hypothesis. Other times, discoveries are made serendipitously. It would be a challenge to find evidence of a linear 'scientific method' in much of advanced physics research, not to mention in many great scientific advances of the past century. Contemporary education literature suggests that a universal scientific method does not exist at all, and that inquiry proceeds in many, varied ways (Alters, 1997; Knorr-Cetina, 1999; McGinn & Roth, 1999). Importantly, recent literature also strongly advocates an *inquiry-based approach* to laboratory pedagogy and learning. Inquiry-oriented laboratories stimulate learners to develop increased independence and are more epistemologically and practically aligned to authentic science. Students focus on independently devising experimental methods and arriving at reasoned findings. Inquiry-based labs can enhance subject understanding and foster positive attitudes toward science and science learning (Chang & Mao, 1999; Luckie et al., 2004). The position in this paper is in accord with that of the

NRC and other contemporary science education literature; that the development of student's inquiry processes is of primary importance in university level science laboratories.

A clear indication that the undergraduate Physics labs may not be adequately challenging students to become independent, inquiry oriented thinkers came in 2002 in a report (Beamish et al., 2002) to the curriculum committee of the Department of Physics from a team led by Beamish, a co-author of this paper. The committee's findings were worrying. Students were, "uniformly negative about their overall laboratory experience, despite liking the hands-on aspects of the lab, the opportunity to work in groups, and their TAs". First year students were especially critical. Only 3 of 240 students considered the lab component of the course excellent. In PHYS 124, the largest first-year physics course with over 1 000 registered students in 2011, 73 out of 87 students rated the lab component at 3 or lower on a 5-point scale. Only 14 out of 87 students found the labs interesting and stimulating. The report proposed that "significant changes" were needed.

From a perusal of the 2011/2012 PHYS 124 laboratory manual it was obvious that the labs were almost entirely confirmatory in orientation and therefore unsatisfactory as authentic physics inquiry learning experiences. For each lab, students received a set of instructions that they were expected to follow closely. There was little stimulus or opportunity for independent thought, and little authentic inquiry. Other problematic issues were also evident regarding the operation of these laboratories. Firstly, the laboratories and the lectures were not well sequenced, with the material being introduced in lectures sometimes weeks after the related lab. Secondly, there was no interaction between the class lecturer and the laboratories. Finally, there was a vast difference in teaching ability and performance of the TAs in different lab sections. Therefore, the situation as it existed was contrary to and unsupportive of inquiry-based approaches that have been shown to foster creativity, interest, enhanced understanding and positive attitudes. Our funded project aimed to begin to address these issues.

THE TEAM BUILDING PROCESS AND MEMBER ROLES

The second and third authors of this paper are both Professors within the Physics Department at the University of Alberta, and are closely involved in teaching within the Department. Both were highly interested and invested in addressing the issues raised in the earlier evaluation/s of the first-year physics laboratories. In November 2010 they approached the first author to ascertain his interest in being involved in the project primarily as an evaluator of the curricular and pedagogical changes that they envisioned. Together, the three authors submitted a funding proposal that was successful.

There was a quite clear distinction in the roles of the authors and such role differentiation contributed to the overall smooth operation of the project. Authors 2 and 3 led the development of the new laboratory curriculum including the activities and tutorials, liaised between the non-academic members of the Physics Department responsible for day-to-day laboratory management, engaged in the training of the TAs regarding the new laboratory activities and tutorials, and organized access to students for the first author. The first author took responsibility for conducting the evaluation of the changes to date. It enabled the Physics Department members to initiate changes to their program and pedagogies, and the external evaluator from the Education Faculty to undertake the evaluation research in an ethical manner that did not compromise the anonymity or confidentiality of the students who provided feedback on those changes.

The proposed solution: the plan and its enactment

The extent to which laboratories are inquiry-oriented laboratories varies along a continuum. At one end of the continuum is the 'confirmation,' recipe-like or method-based lab, within which students have limited responsibility for independent thought or inquiry. At the other end are 'research apprenticeships' within which students, typically post-graduates, are expected to show evidence of considerable independent thought and inquiry as they progress to answer a question that they themselves pose using methods they devise (Windschitl, 2002). This level most closely resembles authentic scientific research. Located between these ends of the continuum are *'guided inquiry'* laboratories. Here, the procedures to solve a problem are decided upon by the student, who receives partial guidance from the instructor. They represent a balanced pedagogical approach for first-year undergraduate laboratories that are populated mainly by students whose experiences are grounded in high school, confirmatory-type studies. *'Guided inquiry'* labs can promote independence and creativity and provide support and intellectual scaffolding for students from instructors.

The team received funding support to introduce A *guided inquiry* based teaching and learning in the first-year physics labs at the University of Alberta. Guided inquiry meant that the students were not to be left to flounder in a 'sink or swim' environment when engaging with the new activities. Rather, they were to be supported by the TAs whose role it was to scaffold their thinking and provide guidance. The implementation of such a philosophy to the laboratories brought with it challenges. There was considerable variation in teaching skill amongst our TAs; we faced highly questionable conditioning and preparation in many students coming out of high school; and it was anticipated that instructors and TAs would encounter the need to address different pedagogical issues than they would in more traditional, 'confirmatory' labs. Inquiry-based learning implies significant changes to existing methods and it was imperative to increase the pedagogical awareness and capabilities of our instructors and TAs.

To begin to address these issues, TA meetings were conducted every Friday at 2PM for the following week's lab. Each meeting lasted about an hour. These meetings were made mandatory for all TAs whereas, in the past, they were optional. The purpose of the meetings was to discuss the pedagogical objectives of the following week's labs, ensure the TAs were familiarized with the equipment to be used, and to discuss any issues or comments the TAs had about the lab that had been completed during the week of the meeting. Suggestions for improvements, for example, to marking, or means to enhance efficiencies were encouraged and often discussed. Four-to-five slide PowerPoint presentations for the TAs regarding forthcoming laboratory and tutorial activities were developed by the instructors, shown at the meeting, and emailed to all TAs for their information and use. The TAs were permitted to make modifications as they saw fit according to their individual teaching styles.

In determining which activities were to be conducted by students in the laboratories the key criteria was that the labs and tutorials needed to be based in engagement in guided inquiry, and not on rote, recipe-following as in the past. The activities needed to link to modern work in physics as much as realistically possible given the low level (first year). They needed to be able to accommodate students who varied considerably in their previous access to and/or experience conducting physics experiments in high school. They needed to avoid 'magic formulas' that the students simply had to be told, without any understanding of where they come from, which was a significant issue in the previous lab format. The question that was to be put to students in the laboratory and tutorial activities was to be, "How, do I solve the problem?" rather than "What is the final answer?" The activities also needed to continually reinforce students' data presentation and data-handling skills, and encourage students' independence though the use of their own portable computers as much as possible, even though lab computers were provided for those needing them. A key variation between 2011/2012 and 2012/2013 classes was that students in the 2012/2013 classes were allowed to take their data and complete their laboratory reports after the lab session had concluded. This was in contrast to previous practice in which they were expected to complete their lab reports prior to leaving the laboratory session.

Tutorials were added to the laboratory schedule, replacing some experimental sessions, with the main intention to provide a source of questions or problems that would be relevant to modern happenings in the field of physics. These were intended to capture the students' imagination, while providing challenging material for independent thought. Additionally, they were meant to push the students' computational and data-handling skills. For example, one tutorial included calculations about the transits of Venus, the most recent transit occurring to great fanfare in 2012, only a few months prior to the tutorial. Another asked students to download images of the Sun from the week prior to their tutorial, taken by NASA's SOHO satellite, and to use the images to calculate the Sun's rotation rate. Therefore, the tutorials offered a flexibility that a lab could not always offer, especially with regards current happening in the physics 'world'. The eventual aim is for future instructors to invent one or two new tutorials each semester, to be added to a collection of such activities for future use and reference. Over the course of the 2012/2013 fall term students engaged in 4 tutorials and 6 laboratory activities, compared with 10 laboratory activities and no tutorials in the previous year and for several years before.

THE EVALUATION OF THE CHANGES MADE

A mixed-method methodology was selected for the evaluation of this project and the effect of the curricular and pedagogical changes. Mixed-methods research is a pragmatic approach to research that allows researchers to "select methods and approaches with respect to their underlying research questions, rather than with regard to some preconceived biases about which research paradigm should have hegemony in social science research" (Johnson & Onwuegbuzie, 2004). This evaluation involved the development and use of a learning environment survey, custom-oriented to undergraduate physics laboratories (Thomas, Meldrum & Beamish, 2013), and interviews. A 23-item instrument, the UPLLES (Undergraduate Physics Laboratory Learning Environment Survey) was developed and validated through (a) factor analysis, using responses of 476 students, and (b) semi-structured interviews with 19 of those students (Thomas, Meldrum & Beamish, 2013). The five sub-scales of the UPLLES are Inquiry Orientation (5 items), Integration (5 items), Material Environment (4 items), Student Community (6 items), and Instructor Support (3 items). Each item on the instrument is scored on a 5-point Likert scale (1 = Almost Never to 5 = Almost Always). Table 1 (Thomas, Meldrum & Beamish, 2013) is a description of each of the five subscales and the learning environment dimensions they represent. Table 2 shows the item-mean values (Min = 1, Max = 5), Cronbach's alpha values, and effect sizes for each of the sub-scales, pre- (2011/2012, $N = 269$) and post-change (2012/2013, $N = 265$).

Table 1: Description of scales and a sample item for each scale on the UPLLES

Scale Name	Description (Extent to which students consider:)	Sample item (In my physics laboratory classes:)
Integration	…that laboratory activities and content are integrated with non-laboratory & theory classes.	…students understand the relevance of what they are learning in their physics lectures.
Student Community	…that students are helpful and supportive of each other and their physics learning.	…students carefully consider the ideas of others in the class.
Inquiry Orientation	…they are asked to engage in inquiry-type investigations and thinking to learn about physics.	…students design their own ways of investigating problems.
Instructor Support	…they are supported and encouraged by laboratory instructors to engage in and improve their physics learning.	…instructors encourage students to think about how to improve their lab performance.
Material Environment	…that the material resources in the physics laboratories are adequate for the performance of the required tasks.	…the materials that students need are readily available.

The UPLLES was used, with interviews, to evaluate the 2011/2012 first-year Physics laboratory environments at the University of Alberta, i.e., pre-pedagogical change.

Table 2: Pre- and post- item mean scores, cronbach alphas and effect sizes for PHYS 124 students' responses to UPLLES classroom environment scale

		Inquiry Orientation	Integration	Material Environment	Student Community	Instructor Support
Pre (2011/2012)	Mean	2.410	3.155	3.725	3.641	2.870
	S.D.	0.749	0.909	0.743	0.733	0.983
	α	0.75	0.76	0.66	0.84	0.71
Post (2012/2013)	Mean	3.379*	4.005*	4.316*	4.135*	3.627*
	S.D.	0.739	0.696	0.541	0.589	0.871
	α	0.77	0.85	0.62	0.80	0.75
	Effect size	1.30	1.05	0.85	1.19	0.82

*$p < .001$

The data analysis confirmed their lack of inquiry orientation. Table 2 shows the pre-pedagogical statistical findings. In summarizing the interviews, students confirmed the 'recipe-like' format of the experiments; "Mostly, we just follow the procedure in the lab manual... much like high school physics, still... we don't get to design anything on our own," and "when you are doing the experiment it's like a step-by-step of what you are supposed to do so that you get close enough to the proper results". They bemoaned the intense nature of the lab experience and the pressure on them to complete all work in three hours; "You were just focusing on rushing and writing up the conclusion as quickly as you can and you're not really thinking about the science behind it", and "The labs are kinda rushed... they don't let you completely immerse yourself in the experience that you are having." Further, they criticized the lack of connection and integration between the lectures and the lab component; "The labs are quite a bit ahead of the class. So sometimes we'll be doing something in the lab and we haven't even touched (it) in class... we were doing waves for the last couple of labs and in class we just started on labs" and "There was a bit of an issue where we were working on a problem in the lab, but that is three weeks ahead and we hadn't talked about it yet... the frustrating part about that is when you haven't learned the concepts and you're being graded on those mistakes." Students confirmed our existing views that the laboratory activities and students' experience with those activities was inadequate to foster the cognition and dispositions we were interested in developing.

Analysis of the statistical data between pre- and post- student populations (Table 1) using independent samples t-test/s shows that the changes initiated by the Physics Department had a significant positive effect on students' perceptions of their experiences and the nature of their laboratory learning environment. The large effect sizes confirm marked changes in students' perceptions. While these findings might seem predicatble, there are very few if any studies that provide anything other than anecdotal evdienvce on the effect of such changes, especially with such large student cohorts. In interviews, the students described the type of thinking they considered was required of them in the 2012/2013 laboratories and tutorials. They reported that they were given a starting point, a problem to solve, and from there they had to determine how to proceed, how to make sense of the problem, how to bring their learning from lectures, e.g., equations, to bear on the problem, and how the TAs, in general, provided guidance through scaffolding support without ever 'telling them the answer,' so that the students had to arrive at the end point themselves. Students in 2012/2013 were much more satisfied with their experience than those the previous year, even though the thinking they were asked to undertake might be considered more challenging, and certainly more inquiry orientated, than previously asked for. Examples of the 2012/2013 students' intimations during the interviews, woven together from their interview transcripts are immediately below. These clearly help identify differences between the perceptions of the 2011/2012 and 2102/2013 cohorts regarding their physics laboratory learning environments.

My labs take the whole three hours and all of the lab report is done after. They don't give you any guidelines. It's like, "This is the answer we want, here's maybe a hint, and then you have to go and figure it out by yourself. In the solar rotation lab, they basically told us what they wanted, with no hint of all of the math behind it and what we needed to use and what different equations to use. We had nothing to start with, just what they wanted [asked for]. And so, most of the stuff that we used was our own thinking... and then the laboratory instructor ended up helping us a lot because we were all clueless as to where to start to approach it. So, it was *all very much starting from scratch. [There was] a lot of talking and trying to figure it out. We take what we have done and what we can measure... there were about five of us trying to work it out together."*

I found that the way the labs were set up in Physics 124, it made me so relaxed that when I came into the labs I was encouraged to to learn about what the topic of the day was. Our laboratory instructor was really good, [saying] "This is a calm environment; you don't have to rush through the three hours." So, you can actually ask questions and learn more about it and learn things that you want to learn out of it, not just the basis of what the lab's about. The procedure for the labs is pretty much left to you. A good thing with the physics labs was that you could read ahead with the notes that your prof posted or you could refresh from the notes that you had already gone through, and then apply that to the lab that you're doing. You had that knowledge and it wasn't just coming out of random places that you had never experienced before.

I think they were looking for us to do a lot of critical thinking, not just how to plug numbers into formulae and spit out more numbers, but [to look at] the concepts behind it and how certain discoveries were made and how we could use these in our daily lives. In physics [labs] there's no ingredient list, there's no formula to follow. You have to figure out what you're doing.

Most of the thinking was, "How do you take a problem and work through it?" Most of it was word problems. They didn't just give you a formula and say "Go with it." YOU had to decide which formula you had to use, because sometimes they gave you a lot of formulas and you had to use one of them. Or sometimes they only gave you one formula and you had to derive the others. So YOU had to figure out which formulas to use and how to do it. I remember one lab, in particular. The quantum tunneling lab. There were a lot of theoretical questions about that, and you really had to think totally 'outside the box' as to how it happens or could possibly happen. In our group it sparked some pretty good discussions.

Concluding comments and implications

This study suggests that substantial change/s can be effected in undergraduate physics laboratory classes in settings where there are large numbers of students taking first year courses and multiple laboratory sections. This is an important finding for undergraduate science education nationally and internationally. It is also clear that new collaborations, in this case those linking Physics and Education faculty can result in positive outcomes for students, faculty and the university and that such collaborations should be promoted within universities. Further activities and studies are planned to build on these results from across other first year physics courses, to refine the activities already developed, and to develop and evaluate training programs for graduate teaching assistants.

References

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching*, 34, 39–55.

Beamish, J. et al. (2002). *Report to the curriculum committee of the undergraduate laboratories review committee.* Department of Physics, University of Alberta.

Chang, C. Y. & Mao, S. L. (1999). Comparison of Taiwan science students' outcomes with inquiry-group versus traditional instruction. *Journal of Educational Research*, 92, 340–346.

Johnson, R. B. & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), 14–26.

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge.* Harvard University Press, Cambridge: MA.

Luckie, D. B. et al. (2004). Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of "Teams and Streams." *Advanced Physiology Education*, 28(4), 199–209.

McGinn, M. K. & Roth, W. M. (1999). Preparing students for competent scientific practice: Implications of recent research in science and technology studies. *Educational Researcher*, 28, 14–24.

National Academy of Sciences. (1996) *The national science education standards.* Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: a guide for teaching and learning.* Washington, DC: Center for Science, Mathematics, and Engineering Education.

Russell, C. B. et al. (2008). Student perceptions of the purpose and function of the laboratory in science: A grounded theory study. *International Journal for the Scholarship of Teaching and Learning*, 2, 1–14.

Thomas, G. P., Meldrum, A. & Beamish, J. (2013). Conceptualization, development and validation of an instrument for investigating elements of undergraduate physics laboratory learning environments: The UPLLES (Undergraduate Physics Laboratory Learning Environment Survey). *European Journal of Physics Education*, 4(4), 28–40.

Weaver, G. C. et al. (2008). Inquiry-based and research-based laboratory pedagogies in undergraduate science. *Nature chemical biology*, 4, 577–580.

Windschitl, M. (2002). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, 86, 112–143.

GREGORY P. THOMAS
Department of Secondary Education

AL MELDRUM
JOHN BEAMISH
Department of Physics, The University of Alberta, Edmonton, Canada

sciED
Scientia in educatione 8(Special Issue), 2017
p. 285–292
ISSN 1804-7106

Sequential Reasoning in Electricity: Developing and Using a Three-Tier Multiple Choice Test

Hildegard Urban

Abstract

Electricity is one of the areas in physics most studied in terms of learning difficulties. Misconceptions are strongly-held, stable cognitive structures, which differ from expert conception and affect how students understand scientific explanations. Therefore, there is a need for tests of conceptual understanding tests which are useful in diagnosing the nature of students' misconceptions related to simple electric circuits and, in consequence, can serve as a valid and reliable measure of students' qualitative understanding of simple electric circuits. As ordinary multiple choice tests with one-tier may overestimate the students' correct as well as wrong answers, two- and three-tier tests were developed by researchers. Although, there is much research related to students' conceptions in basic electricity, there is a lack of instruments for testing basic electricity concepts of students at grade 7, especially addressing an electric circuit as a system for a simple circuit of resistors and lamps in series. To address this gap, the context of the present study is an extension to the development of an already existing instrument developed by the author for testing electricity concepts of students at grade 7, specifically focusing on only two specific aspects in depth: first, to develop three-tier items for figuring out sequential reasoning, and second, to distinguish between misconceptions and lack of knowledge. The participants of the study included 339 secondary school students from grade 7 to 12 after instruction on electricity. Surprisingly, there are no dependences on students' misconceptions either according to their gender or to their age. In conclusion, the findings of the study suggest that four items for uncovering students' sequential reasoning can serve as a valid and reliable measure of students' qualitative understanding of the systemic character of an electric circuit.

Key words: three-tier concept test, sequential reasoning in electricity, uncovering students' conceptual understanding.

THEORETICAL BACKGROUND

Research findings suggest that there are three categories of student difficulties in basic electricity: 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). In general, students come to the classroom with various misconceptions which may critically influence their understanding of scientific concepts and explanations (Hammer, 1996). In other words, students may have various, often pre-conceived misconceptions about electricity, which stand in the way of learning. The most two resistant obstacles seem to be to view a battery as a source of constant current and to not consider a circuit as a system (Dupin & Johsua, 1987). Closset introduced the term *sequentialreasoning* which appears to be widespread among students (Closset, 1983; Shipstone, 1984). There is some evidence that sequential reasoning at least partially is developed at school (Shipstone, 1988) and reinforced by the teacher (Sebastia, 1993). Using the metaphor of a fluid in motion (Rosencwajg, 1992) and highlighting that electricity leaves the battery at one terminal and goes to turn on the different components in the circuit successively does not support students in viewing a circuit as a system (Brna, 1988) On the contrary, this linear and temporal processing prevents students from making functional connections between the elements of a circuit and from viewing the circuit structure as a unified system (Heller & Finley, 1992). Surprisingly, research findings do not indicate a different development of sequential reasoning according to age (Riley, Bee & Mokwa, 1981). Similar conceptions are also held by adults and some teachers (Bilal & Erol, 2009).

Therefore, there is a need for a diagnosis instrument to get information about students' preconceptions and also to evaluate the physics classroom. In order to identify and measure students' misconceptions about electricity different approaches have been made. In contrast to interviews, diagnostic multiple choice tests can be immediately scored and applied to a large number of subjects. Pesman and Eryilmaz (2010) used the three tier test methodology for developing the SECDT (Simple Electric Circuits Diagnostic Test). In order not to overestimate students' right as well as wrong answers, researchers developed two- and three-tier tests (Pesman & Eryilmaz, 2010; Urban-Woldron & Hopf, 2012). Starting from an ordinary multiple choice questions in the first tier, students are asked about their reasoning in the second tier, and students estimate their confidence in their answers in the third-tier.

An extensive review of literature according to appropriate test instruments showed that they either did not achieve psychometric requirements or were developed only for high school or college students. In view of a lack of instruments for testing electricity concepts of students at grade 7 and for being suitable for the Austrian physics curriculum, the author developed a diagnostic instrument with some two-tier items for assessing students' conceptual understanding as well as its potential use in evaluating curricula and innovative approaches in physics education (Urban-Woldron & Hopf, 2012).

AIM AND RESEARCH QUESTION

Many students seem to be unable to consider a circuit as a whole system, where any change in any of the elements definitely affects the whole circuit. In consequence, they often demonstrate 'local reasoning' by focusing their attention only on one specific point in the circuit and by ignoring what is happening elsewhere in the circuit. In circuits with resistors in parallel students often believe that the current is divided into two equal parts at each junction neither taking into account the values of the resistors nor concentrating on the whole number of resistors. Additionally, students show ‘sequential reasoning’, by which they believe that for example, if a resistor in a circuit is replaced by a resistor with higher value, only elements coming after the resistor are affected.

For gaining a correct vision of student understanding, it is crucial to discover what students actually do not know and what kind of alternative conceptions they have. Therefore, also for the researcher the wrong answers and the associated explanations of the students are much more interesting and usable than the correct answers. Consequently, the context of this study is an extension to the development of an already existing instrument for testing the concepts of electricity of students at grade 7 in two specific aspects: first, to develop items for figuring out sequential reasoning, and second, to distinguish between misconceptions and lack of knowledge. The following broad research question was addressed:

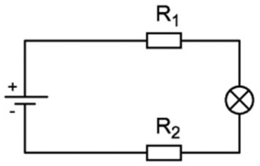
Can a three-tier multiple choice test be developed that is reliable, valid, and uncovers certain students’ misconceptions related to sequential reasoning?

Method

In order to develop a reliable tool to identify students’ misconceptions related to sequential reasoning and in addition to previous studies (Urban-Woldron & Hopf, 2012), the author first conducted interviews based on a literature review, using both structured and open-ended questions. In an initial stage a 10-item questionnaire was developed, including 10 two-tier items (meaning question plus follow-up question, an example is provided in Figure 1). Subsequently, only four out of those ten items finally constituted the test instrument used in this present study, assessing students’ understanding of the systemic character of a simple electric circuit with three-tier items.

A lamp and two resistors are connected to a battery.

a) What will happen to the brightness of the lamp if R_1 is increased and R_2 remains constant?



☐ The brightness of the lamp decreases.

☐ The brightness of the lamp remains constant.

☐ The brightness of the lamp increases.

b) How would you explain your reasoning?

☐ It is the same battery. Therefore, the same current is delivered.

☐ A change of the resistor only influences the brightness of the lamp if the lamp is behind the resistor.

☐ Any change of the resistor influences the brightness of the lamp independently of its position in the circuit.

c) Are you sure about your answer to the previous two questions?

☐ highly certain	☐ rather certain	☐ rather uncertain	☐ highly uncertain

Figure 1: Sample Item A

In the first round of evaluation with 10 teachers and 113 students (grade 8, 58 female), the questionnaire was reduced to 7 items, each extended with a third tier asking for students‘ confidence in answering each question. After a test run with 339 students of grade 7 to grade 12 from secondary schools across Austria following formal instruction (183 female, mean age 14.7 years, standard deviation 1.7 years) results were evaluated with the software programs SPSS and AMOS. In a polishing round, additional interviews were used to optimize the test 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 werecalculated to address students' misconceptions. Finally, for constituting the latent variable "sequential reasoning", four items were used.

In the following, we present a three-tiered item (see Figure 2), 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 answers provided have not been thought up by the researcher but are based both on literature review (Dupin & Johsua, 1987; Closset, 1983; Shipstone, 1984, 1988) and clarifying interviews with students.

PARTICIPANTS AND SETTING

The participants of the study included 339 secondary school students from grade 7 to 12 (183 female; mean age$=$ 14.7 years, $SD = 1.7$; 18 forms, 7 schools) after instruction on electricity. Nine teachers were randomly asked to administer a paper and pencil test to their students with 7 three-tiered items related to sequential reasoning. Figure 2 shows the distribution of the students amongst grades.

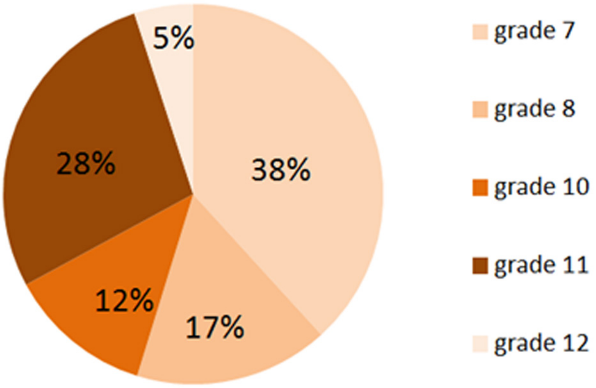


Figure 2: Distribution of students and grades

DATA ANALYSIS

Starting with descriptive analyses, analyses of variance, confirmatory factor analyses, and regression analysis using the software SPSS and AMOS were conducted.

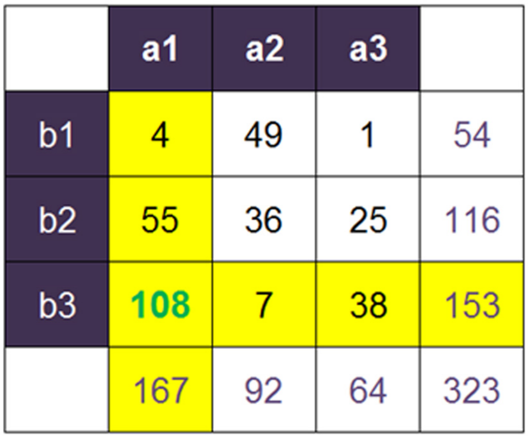
RESULTS

Obviously, the correct answer for item A (see Figure 2) would be a1 and b3. 108 students out of 323 who answered all four items (33.4 %) provided a correct answer to the first two tiers of item A.A closer look at the numbers in table 1 shows that 51.7 % or 167 students actually answered the first tier correctly, but 59 out of these

167 students or 35.3 % provided a wrong reason. Consequently, more than one third of the correctly responding students on the first tier can be added to so-called false positives. On the other hand, 153 students chose the right explanation, whereas only 70.6 % of these students also gave a correct answer on the first tier. Therefore, we critically overestimate students' knowledge if we only look at one tier. Overall, 30 students are highly certain, 105 are rather certain, 88 are rather uncertain, and 100 are highly uncertain about their answers. 11 of the highly certain students and 27 of the rather certain ones give the correct answer for the first and the second tier, whereas only 8 of the highly uncertain students answer this item correctly. In other words, the results suggest that some students may be presumably guessing and sometimes they indeed guess right on both sections. Consequently, if we want to completely exclude guessing anyway we have to focus only on students with high certainty reported.

Table 1 gives an overview of the three answer options a1, a2, and a3 and the three associated alternatives b1, b2, and b3 for the reasoning.

Table 1: Distribution of answers and reasons for item A



	a1	a2	a3	
b1	4	49	1	54
b2	55	36	25	116
b3	108	7	38	153
	167	92	64	323

Next, three misconceptions which were derived connecting specific answers and explanations will be illustrated here:

Misconception #1 (Answers a1, b2)

In this misconception the student chooses the right answer, but based on the observation that the lamp is behind the resistor when electricity is moving round the circuit from the positive to the negative terminal. More than a third of students who identified that the bulb will be dimmer gave this erroneous explanation. 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 and #3 (Answers a2, b2 or b1)

Here, the student probably thinks that a constant amount of current leaves the battery at the negative end and reaches the lamp before it arrives at the increased resistor. 36 out of 92 students think sequentially. 49 students out of those 92 view the battery as a source of constant current not considering any influence from the resistance on the intensity of current. 38 students respond in a false-negative way as they choose the correct explanation but think that an increased resistor produces an increased brightness of the lamp.

Construct validity was evaluated through factor analysis. Confirmatory factor analysis with AMOS, using the maximum-likelihood-method and including specific combinations of answers due to the first and second-tier of four different test items, resulted in a χ^2-value of 5.805, which was not significant ($p = .221$). Therefore, a latent variable 'sequential reasoning' could be established (see Figure 3).

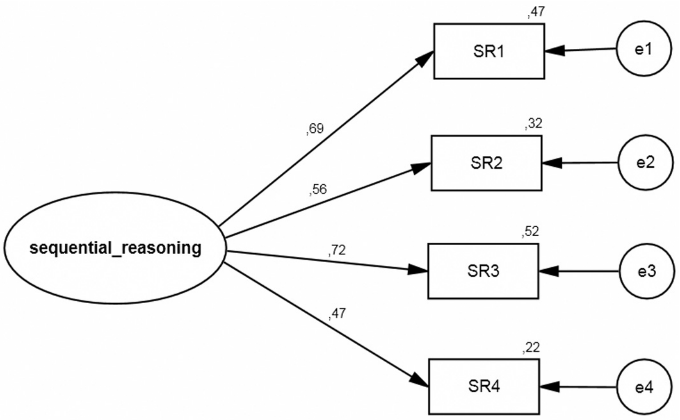


Figure 3: Latent Variable 'sequential reasoning'

As mentioned above, students from 18 forms in 7 schools took part in the study. Consequently, nine teachers were involved. Findings from ANOVA reveal a main effect for correct answers concerning all four items A to D on the particular school, respectively on the particular teacher. Surprisingly, there are no dependences on students' conceptions both related to correct answers and misconceptions neither according to their gender nor to their age.

Furthermore, regression analysis, where items A to C[1] were used to predict sequential reasoning for item D, suggests that those three factors together explain 31 % of the variance for item D ($F(3, 338) = 49.89$, $p < .000\,1$) and are significant individual predictors of students' sequential reasoning for item D (see Figure 4).

A resistor and two lamps are connected to a battery.

a) What will happen to the brightness of the lamps if R is increased?

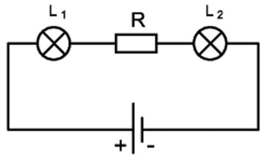
☐ L_1 remains constant, L_2 decreases.

☐ L_1 decreases, L_2 remains constant.

☐ The brightness of both lamps increases.

☐ The brightness of both lamps decreases.

☐ The brightness of both lamps remains constant.



b) How would you explain your reasoning?

☐ A change of the resistor only influences the brightness of the lamp if the lamp is behind the resistor.

☐ Any change of the resistor influences the brightness of both lamps.

☐ It is the same battery. Therefore, the same current is delivered.

☐ Both lamps have a direct connection to the battery. Therefore, the resistor has no effect on the lamps.

c) Are you sure about your answer to the previous two questions?

☐ highly certain	☐ rather certain	☐ rather uncertain	☐ highly uncertain

Figure 4: Item D

---

[1] Colleagues interested in items B and C are encouraged to ask the author.

CONCLUSIONS AND IMPLICATIONS

In conclusion, the findings of the study suggest that four items for uncovering students' sequential reasoning can serve as a valid and reliable measure of students' qualitative understanding of the systemic character of an electric circuit. Obviously, if researchers or teachers use only one tier in a multiple choice instrument, they definitely overestimate correct answers and in consequence, gain of a wrong impression of student understanding. The present instrument can be used as a tool both for teachers and researchers to gain a correct vision of student understanding. It can be easily administered to a large number of students and could be used as a research tool for assessing new curriculum materials or teaching strategies. Although there is some evidence that the conceptual test is reliable, valid and objective, there have to be a few improvements. Additional interviews highlighted that the wording on the first tier may not be perfectly comprehensible to students. A student may be very confident about his or her answer on the third tier but not about his or her given explanations on the second tier. Furthermore, the interviews which were carried out to develop the distractors for the explanations revealed that some of the teachers tend to introduce the direction of the current from the positive to the negative terminal of the battery, whereas others use the direction of the negative charges from the negative to the positive pole. Therefore, further improvements of the conceptual test instrument will take these limitations of the present study into consideration by using an arrow to indicate the direction of the current.

REFERENCES

Bilal, E. & Erol, M. (2009). Investigating students' conceptions of some electricity concepts. *Latin American Journal for Physics Education*, 3(2), 193–201.

Brna, P. (1988). Confronting misconceptions in the domain of simple electric circuits. *Instructional Science*, 17, 29–55.

Closset, J. L. (1983). Sequential reasoning in electricity. In *Proceedings of the International Workshop on Research in Physics Education, La Londe les Maures.* Paris: Editions du CNRS.

Dupin, J. J. & Johsua, S. (1987). Conceptions of French pupils concerning electric circuits: Structure and evolution. *Journal of Research in Science Teaching*, 24(9), 791–806.

Hammer, D. (1996). More than misconceptions: Multiple perspectives on student. Knowledge and reasoning, and an appropriate role for educational research. *American Journal of Physics*, 64(10), 1316–1325.

Heller, P. M. & Finley, F. N. (1992). Variable uses of alternative conceptions: A case study in current electricity. *Journal of Research in Science Teaching*, 29(3), 259–275.

McDermott, L. C. & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example form introductory electricity. Part I: investigation of student understanding. *American Journal of Physics*, 60(11), 994–1003.

Pesman, H. & Eryilmaz, A. (2010). Development of a three-tier test to assess misconceptions about simple electric circuits. *Journal of Education Research*, 103(3), 208–222.

Riley, M. S., Bee, N. V. & Mokwa, J. J. (1981). Representations in early learning: the acquisition of problem-solving strategies in basic electricity and electronics. In *Proceedings of the International Workshop on Problems Concerning Students' Representations of Physics and Chemistry Knowledge, Ludwigsburg* (107–173). Ludwigsburg: Pädagogische Hochschule.

Rosencwajg, P. (1992). Analysis of problem solving strategies on electricity problems in 12 to 13 year olds. *European Journal of Psychology of Education*, 7(1), 5–22.

Sebastia, J. M. (1993). Cognitive mediators and interpretations of electric circuits. In *The proceedings of the third international seminar on misconceptions and educational strategies in science and mathematics.* Ithaca, NY: Cornell University.

Shipstone, D. M. (1984). A study of children‘s understanding of electricity in simple DCcircuits. *European Journal of Science Education*, 6, 185–198.

Shipstone, D. M. (1988). Pupils' understanding of simple electric circuits: Some implications for instruction. *Physics Education*, 23, 92–96.

Urban-Woldron, H. & Hopf, M. (2012). Entwicklung eines Testinstruments zum Verständnis in der Elektrizitätslehre [Developing a multiple choice test for understanding basic electricity]. *Zeitschrift für Didaktik der Naturwissenschaften*, 18, 201–227.

HILDEGARD URBAN
University College of Teacher Education Lower Austria

Scientia in educatione 8(Special Issue), 2017
p. 293–300
ISSN 1804-7106

Validating the Force Concept Inventory with Sub-Questions: Preliminary Results of the Second Year Survey

Jun-ichiro Yasuda, Masa-aki Taniguchi

Abstract

We address the validity of the FCI, that is, whether respondents who answer FCI questions correctly have an actual understanding of the concepts of physics tested in the questions. We used sub-questions that test students on concepts believed to be required to answer the actual FCI questions. Our sample size comprises about five hundred respondents; we derive false positive ratios for pre-learners and post-learners, and evaluate the significant difference between them. Our analysis shows a significant difference at the 95 % confidence level for Q.6, Q.7, and Q.16, implying that it is possible for post-learners to answer three questions without understanding the concepts of physics tested in the questions; therefore, Q.6, Q.7 and Q.16 are invalid.

Key words: physics education research, force concept inventory, validation.

INTRODUCTION

Numerous types of diagnostic tools have been studied to examine how much students have learnt physics. The Force Concept Inventory (FCI) is one of the most important instruments for assessing students' understanding of the Newtonian conceptual framework (Hestenes, Wells & Swackhamer, 1992; Halloun & Hestenes, 1985a, 1985b; Huffman & Heller, 1995; Heller & Huffman, 1995). The FCI is a 30-item, five-choice survey that can be solved without the use of equations. Further, the distractors in the questions are constructed based on the naive conceptions about mechanics.

When conducting a survey using a diagnostic tool such as the FCI, it is first necessary to analyse its validity (Redish, 2003: p. 96). Validity refers to whether the instrument measures what it claims to measure. In the case of the FCI, we must investigate whether the FCI accurately assesses students' conceptual learning of Newtonian mechanics.

The FCI has previously been validated from various standpoints. Hestenes and colleagues evaluated the validity of the wording and diagrams in its questions (Hestenes, Wells & Swackhamer, 1992; Hestenes & Halloun, 1995), while Rebello and Zollman analysed the validity of the distractors in the questions by comparing students' responses to four FCI open-ended questions (Rebello & Zollman, 2004). Morris and colleagues also evaluated the validity of the distractors by analysing the item response curves (Morris et al., 2006, 2012), and Stewart and colleagues validated the contexts of the questions using a ten-question context-modified test (Stewart, Griffin & Stewart, 2007). Yasuda and colleagues interviewed students and found that some students were able to provide the correct answer to Q.6, Q.7 and Q.16 even when using the incorrect reasoning (Yasuda, Uematsu & Nitta, 2012).

In our approach, we use a decision table to clear the problem (Table 1). In Table 1, the rows mean whether a student answers an FCI question correctly or not, and the columns mean whether the student understands the concept tested in the FCI question or not. False positives refer to correct answers provided by students who do not understand the physics concept being tested in the questions [1]. False negatives, by contrast, refer to incorrect answers provided by students who understand the physics concept tested in the question. The FCI question may be valid if the true positives and true negatives are many enough, and the FCI question may not be valid if the false positives and false negatives are many enough.

Table 1: Decision Table of an FCI question

	Understanding	NOT Understanding
Correct	True positive	False positive
Incorrect	False negative	True negative

From Table 1, we tackle the following 3 issues:

1. **How can we define understanding?**
   The definition of the word "understanding" is one of the difficult problems of the cognitive science. In our study, we will define understanding operationally by means of decomposed questions of the original FCI question.
2. **How can we evaluate the amount of false answers?**
   There is a well-known statistical variable to quantify the amount of false answers. We will explain and use it later.

3. **With the variables, how can we evaluate the validity?**
   Using the statistical variables, we need a criterion or a standard value to judge whether an FCI question is valid or not. In order to decide the criterion, we form a hypothesis on this issue later.

In simple terms, our research question examines whether students who respond correctly to an FCI question, understands the physics concept that a question is meant to test. We explain our methods in order of the three issues described above.

METHOD 1: DEFINITION OF UNDERSTANDING

Usually, students answer an FCI question and we check whether the answer is correct or not. However, we cannot judge if the student understands the concept tested in the question. Therefore, we decompose an FCI question into a series of cognitively sequenced questions (Figure 1). We refer to these questions as *sub-questions*. If a student answers all of the sub-questions correctly, we assume that he or she has an understanding of the physics concept tested. The decision table of answers with sub-questions is presented in Table 2.

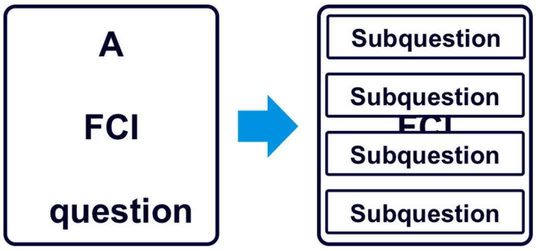


Figure 1: Decomposition of an FCI question

Table 2: Decision Table of an FCI question with sub-questions (SQs)

	Answer all SQs correctly	Answer not all SQs correctly
Correct	True positive	False positive
Incorrect	False negative	True negative

Which of the eight choices best represents the direction of the following variables, just after the string breaks? If you think a variable is zero, write 9.
SQ1. Force acting on the ball
SQ2. Acceleration of the ball
SQ3. Velocity of the ball

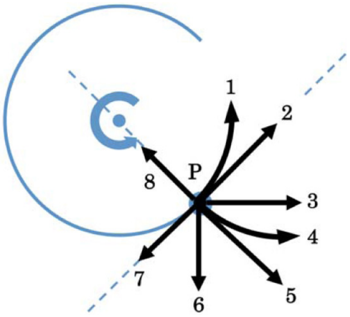


Figure 2: Outline of the sub-questions (SQs) of FCI Q.7

As an example, we show the outline of the sub-question of the FCI Q.7 in Figure 2. The original FCI Q.7 probes students to comment on the trajectory of the ball after the string breaks. The sub-questions presented in Figure 2 gives more direct information such as force, acceleration and the velocity of the ball after the string breaks [2].

METHOD 2: QUANTIFICATION OF FALSE POSITIVES

We analyze the false positives by evaluating a well-known statistical variable, *false positive ratio*. If event A represents answering an FCI question correctly and event B represents answering all the related sub-questions correctly, then the false positive ratio of that question is defined as follows:

$$P(A \mid \mathrm{NOT}\, B) = \frac{N(A \text{ and } \mathrm{NOT}\, B)}{N(\mathrm{NOT}\, B)}$$

where $N(A \text{ and } \mathrm{NOT}\, B)$ is the number of students who answered an FCI question correctly and answered more than one of the sub-questions incorrectly, and $N(\mathrm{NOT}\, B)$ refers to the number of students who answered more than one of the sub-questions incorrectly. In this case, the false positive ratio can be interpreted as the identification of the subgroup that does not understand the physics concept and calculating the percentage of correctly answered questions (Figure 3).

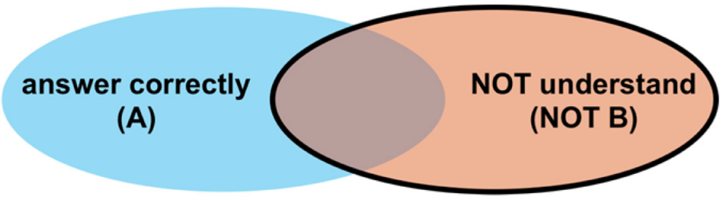


Figure 3: Venn diagram about false positive ratio

METHOD 3: CRITERION OF VALIDITY

We need a criterion, namely a reference value, to relate the false positive ratio to the validity. The reference value is the "ideal" probability with which a student who does not understand the concept tested answers correctly. If a false positive ratio of an FCI question is much larger than the reference value, the FCI question is judged to be invalid.

The simplest reference value is the probability to answer correctly by random guessing, that is, $1/5 = 0.2$. However, students who misunderstand the concept might tend to choose a wrong answer if the distractors of the question are well constructed, or these might tend to choose a right answer if the distractors of the question are not well constructed. In the former case, the ideal probability is less than 0.2, and in the latter case, the ideal probability is more than 0.2.

Since we need to separate the effect of distractors, we take, as the reference value for each question, the probability with which a student who *has not learnt* (pre-learner) the concept tested but answers correctly: $\mathrm{FPR}_{\mathrm{pre}}$ [3]. This value is then compared with the probability with which a student who *has learnt* (post-learner) the concept tested and answers correctly: $\mathrm{FPR}_{\mathrm{post}}$. If the structure of the question is valid, it follows that only if students cannot understand the physics concept will they answer incorrectly, except in cases of coincidence. Therefore, if we choose the subgroups that do not understand the physics concept tested from both pre-learners and post-learners, the percentage of questions answered correctly for each subgroup should be comparable. However, there is one case in which $\mathrm{FPR}_{\mathrm{pre}}$ and $\mathrm{FPR}_{\mathrm{post}}$ are not comparable i.e. when the post-learner responds correctly by using an incorrect physics concept or by remembering the correct answer of a similar question. In this case, the false positive ratio of post-learners could become large. Therefore, if $\mathrm{FPR}_{\mathrm{post}}$ is significantly larger than $\mathrm{FPR}_{\mathrm{pre}}$, we judge that the question is in valid because post-learners can correctly answer the question even if they have no understanding of the physics concept tested.

We can explain this criterion from another standpoint. We begin with forming the following hypothesis: if an FCI question is valid, the FCI question cannot distinguish whether the student has already learnt the concept or not when a student does not understand the concept tested [4]. In this case, the false positive ratio of the pre-learners takes similar value to the false positive ratio of the post-learners. If we take the contraposition of this hypothesis, it follows that an FCI question is invalid if there is a significant difference between the value of the false positive ratio of pre-learners and the false positive ratio of the post-learners. The outline of this logic is shown in Figure 4.

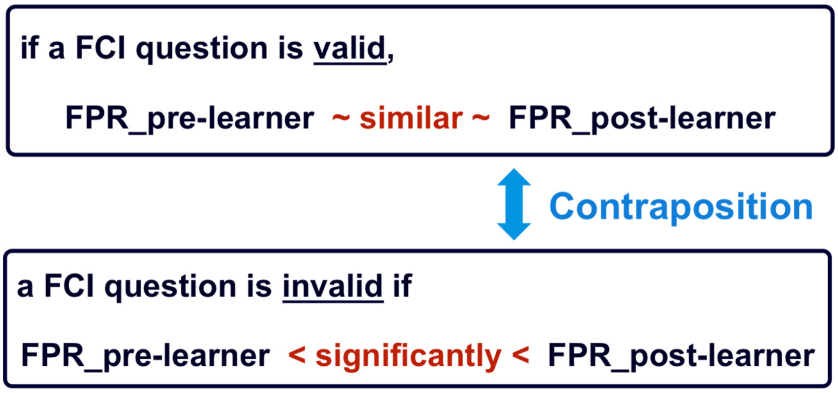


Figure 4: Outline of the logic about our criterion of validity

Table 3: False positive ratios of the pre- and post- learners in this and previous survey

	Q.5	Q.6	Q.7	Q.16
$\mathrm{FPR}_{\mathrm{pre}}$ (2013)	0.11	0.576	0.35	0.13
$\mathrm{FPR}_{\mathrm{post}}$ with CL95 % error (2013)	0.08 ± 0.06	0.653 ± 0.067	0.61 ± 0.07	0.52 ± 0.05
Significant difference	NO	YES	YES	YES
$\mathrm{FPR}_{\mathrm{pre}}$ (2012)	...	...	0.39	0.26
FPR_{post} with CL95 % error (2012)	...	...	0.71 ± 0.13	0.50 ± 0.14
Significant difference	...	...	YES	YES

SETTINGS

DATA COLLECTION

We surveyed 524 students at one public university (Gifu U.) and three private universities (Meijo U., Kansai U. and Ritsumeikan U.) from April to June 2013. Respondents comprised students from different departments (e.g.: engineering, agriculture, human studies), and most were students in the university's physics classes (e.g., calculus based mechanics, general physics). The students were given no incentive to participate (in the form of money or grade points).

SURVEYED QUESTIONS

We surveyed the questions that showed false positives from our previous interview study (Yasuda, Uematsu & Nitta, 2012). The questions are Q.6, Q.7, and Q.16. For example, students were able to provide the correct answer to Q.16 even when using the incorrect reasoning that the forces were balanced because the two vehicles were moving at a constant speed. Similar shortcomings have been highlighted by other studies (Thornton et al., 2009; Scott, Schumayer & Gray, 2012). In addition to these questions, for comparison purposes, we surveyed Q.5, which showed no false positives in the interview. The physics concepts tested in each question are as follows; Q.5: circular motion, Q.6: circular motion, Q.7: circular motion, Q.16: Newton's third law (Hestenes & Jackson, 1992).

RESULTS

The results of our survey are presented in Table 3 which includes the errors of the false positive ratios of the post-learners ($\mathrm{FPR}_{\mathrm{post}}$) at the confidence level 95 %. If a false positive ratio of the pre-leaners ($\mathrm{FPR}_{\mathrm{pre}}$) is out of the error range, we judge that there is a significant difference between the $\mathrm{FPR}_{\mathrm{post}}$ and the $\mathrm{FPR}_{\mathrm{pre}}$. With this criterion, we can see that there is a significant difference on Q.6, Q.7, and Q.16, and there is no significant difference on Q.5. Since Q.5 is the question for comparison, these results are consistent with our previous results. As for Q.6, the $\mathrm{FPR}_{\mathrm{pre}}$ is just outside of the error bar, because the $\mathrm{FPR}_{\mathrm{pre}}$ is considerably large. We think this is because the pre-learners can correctly answer Q.6 with knowledge from their daily experience.

We also show in Table 3 the results of our previous survey carried out in 2012 (Yasuda & Taniguchi, 2013). In this survey, we used similar sub-questions as for Q.7 but fewer respondents ($N = 111$). With the Table 3 and its plot, Figure 5, it is clear that these two surveys are consistent and the precision of the data is improved.

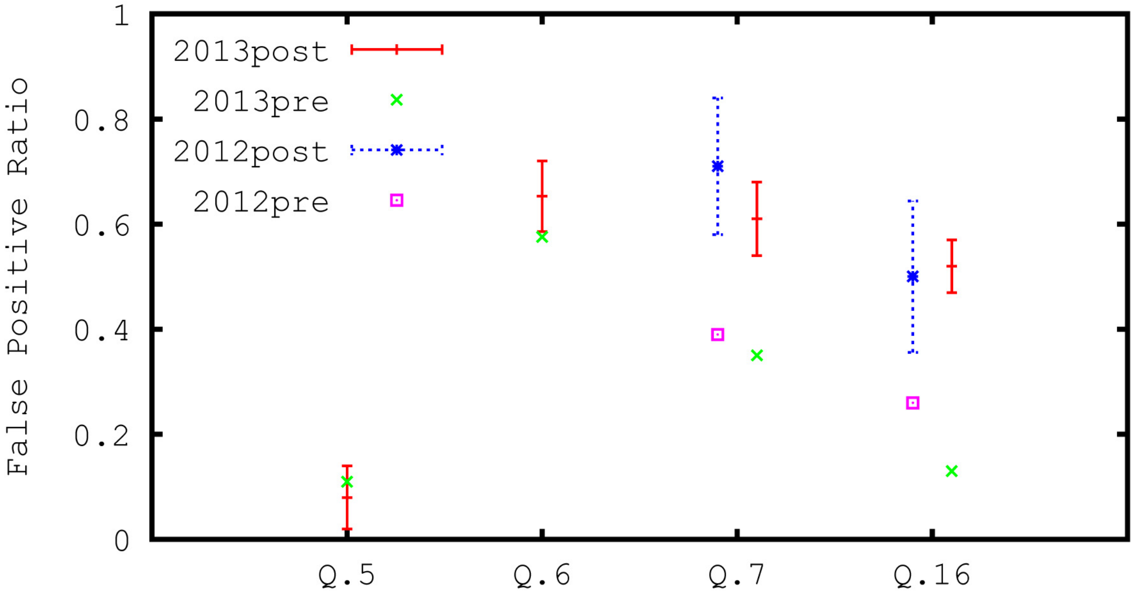


Figure 5: Plot of Table 3. The results of the post-learners are displayed with error bars at 95 % confidence level. The number of respondents is 524 for the survey in 2013 and is 111 for the survey in 2012

CONCLUSIONS

We evaluated the validity of the FCI using sub-questions and the false positive ratio. The false positive ratios of Q.6, Q.7 and Q.16 indicated that these questions are inadequate at the 95 % confidence level. This result implies that it is possible for post-learners to answer these questions without understanding the concepts of physics tested in the questions. This might be because the post-learners can correctly answer questions by using an incorrect physics concept or by remembering the correct answer of a similar question [5].

On the other hand, the false positive ratio of Q.5 indicated that Q.5 is a valid question and we have found no sign of the false positive on the other 26 questions from the interview study. Therefore, we can expect that 90 % of the FCI questions are adequate.

As part of future work, we need to confirm whether those 26 questions are adequate. Moreover, as for the generality, we need to confirm whether our results are true for the students in other countries. We also might need to confirm whether our results are changed if we use different types of sub-questions and evaluate the validity of the sub-questions. However, we should also think how far one should evaluate the sub-questions.

Further future work includes a plan to quantify the validity and estimate the systematic error of the total FCI score. The validation of the FCI has suggested the modification of the inadequate questions, but it might be difficult to compare the data of the modified FCI with the accumulated data. Instead, it will be better to evaluate the systematic error of the FCI from the evaluation of the validity. With this evaluation, we can continue to use the present FCI with reliable limitation.

REFERENCES

Halloun, I. & Hestenes, D. (1985). The initial knowledge state of college physics students. *Am. J. Phys.*, 53(11), 1043–1055.

Halloun, I. & Hestenes, D. (1985): Common sense concepts about motion. *Am. J. Phys.*, 53(11), 1056–1065.

Hestenes, D. & Halloun, I. (1995). Interpreting the force concept inventory: A response to March 1995 critique by Huffman and Heller. *Phys. Teach.*, 33(8), 502–506.

Heller, P. & Huffman, D. (1995). Interpreting the force concept inventory: A reply to Hestenes and Halloun. *Phys. Teach.*, 33(8), 503–511.

Hestenes, D. & Jackson, J. (1992). Revised Table II for the Force Concept Inventory. Available at http://modeling.asu.edu/R&E/Research.html

Hestenes, D., Wells, M. & Swackhamer, G. (1992). Force concept inventory. *Phys. Teach.*, 30, 141–158.

Huffman, D. & Heller, P. (1995). What does the force concept inventory actually measure? *Phys. Teach.*, 33(3), 138–143.

Morris, G. A., Branum-Martin, L., Harshman, N., Baker, S. D., Mazur, E., Dutta, S., Mzoughi, T., & McCauley, V. (2006). Testing the test: Item response curves and test quality. *Am. J. Phys.*, 74(5), 449–453.

Morris, G. A., Harshman, N., Branum-Martin, L., Mazur, E., Mzoughi, T., & Baker, S. D. (2012). An item response curves analysis of the Force Concept Inventory. *Am. J. Phys.*, 80(9), 825–831.

Rebello, N. & Zollman, D. (2004). The effect of distractors on student performance on the force concept inventory. *Am. J. Phys.*, 72(1), 116–125.

Redish, E. (2003). *Teaching Physics with the Physics Suite.* Hoboken: Wiley.

Scott, T. F., Schumayer, D. & Gray, A. R. (2012). Exploratory factor analysis of a Force Concept Inventory data set. *Phys. Rev. ST Phys. Educ. Res.*, 8(2), 020105-1–020105-10.

Stewart, J., Griffin, H., & Stewart, G. (2007). Context sensitivity in the force concept inventory. *Phys. Rev. ST Phys. Educ. Res.*, 3, 010102-1–010102-6.

Taniguchi, M. & Yasuda, J. (2014). Quantitative Validation of Japanese Translation of Force Concept Inventory using Sub-Questions. *Journal of the Physics Education Society of Japan (in Japanese only)*, 62(4), 226–231.

Thornton, R. K., Kuhl, D., Cummings, K. & Marx, J. (2009). Comparing the force and motion conceptual evaluation and the force concept inventory. *Phys. Rev. ST Phys. Educ. Res.*, 5(1), 010105-1–010105-8.

Yasuda, J. & Taniguchi, M. (2013). Validating two questions in the Force Concept Inventory with subquestions. *Phys. Rev. ST Phys. Educ. Res.*, 9(1), 010113-1–010113-7.

Yasuda, J., Uematsu, H., & Nitta, H. (2012). Validating a Japanese version of the Force Concept Inventory. *Lat. Am. J. Phys. Educ.*, 6(1), 89–94.

NOTES

[1] The FCI has five multiple-choice answers per question; therefore, if a respondent chooses the correct answer randomly, false positives will appear in 20 % of his or her answers. Thus, we should focus on highly frequent false positives.

[2] You can see the sub-question of Q.16 in Yasuda & Taniguchi (2013), and you can get the original FCI questions in the following website of the American Modeling Teachers Association,
http://modelinginstruction.org/researchers/evaluation-instruments/fci-and-mbt/

[3] From the questionnaire responses, we determined whether students had studied the concept (for example, Newton's third law or uniform circular motion etc.) tested in FCI questions. If students answered yes to having studied either concept, we called them post-learners and pre-learners otherwise.

[4] If we compare this hypothesis to the quantum states, this hypothesis is equal to the statement that the state: | not understanding | pre-learner > is degenerate with the state: | not understanding | post-learner > under the operator: FCI.

[5] You can see the following study in Taniguchi & Yasuda (2014), in which we sufficiently developed the current analysis and added new results.

JUN-ICHIRO YASUDA
Center for General Education, Gifu University, Gifu, Japan

MASA-AKI TANIGUCHI
Comprehensive Scientific Education Center, Meijo University, Nagoya, Japan

Scientia in educatione

Scientific Journal for Science and Mathematics Educational Research

Published by Karolinum Press, Prague, Czech Republic
http://www.scied.cz

Editor in Chief (Charles University, Prague)
doc. RNDr. Naďa Vondrová, Ph.D.

Editors (Charles University, Prague)
prof. RNDr. Hana Čtrnáctová, CSc.
doc. RNDr. Leoš Dvořák, CSc.
prof. RNDr. Jarmila Novotná, CSc.
PhDr. Martin Rusek, Ph.D.
doc. RNDr. Vasilis Teodoridis, Ph.D.

Editorial Board
prof. RNDr. Pavel Beneš, CSc. (Charles University, Prague)
Dr. John Carroll (Nottingham Trent University, Great Britain)
assoc. prof. Robert Harry Evans (University of Copenhagen, Denmark)
RNDr. Eva Hejnová, Ph.D. (University of J. E. Purkyně, Ústí nad Labem)
doc. PhDr. Alena Hošpesová, Ph.D. (University of South Bohemia in České Budějovice)
Dr. Paola Iannone (University of East Anglia, Norwich, Great Britain)
Prof. Dr. Rainer Kaenders (Rheinische Friedrich-Wilhelms-Universität Bonn, Germany)
RNDr. Alena Kopáčková, Ph.D. (Technical University in Liberec)
PhDr. Magdalena Krátká, Ph.D. (University of J. E. Purkyně, Ústí nad Labem)
PaedDr. Svatava Kubicová, CSc. (Ostrava University)
prof. RNDr. Ladislav Kvasz, Dr. (Charles University, Prague)
Prof. Dr. Martin Lindner (Martin Luther University Halle-Wittenberg, Germany)
prof. RNDr. Danuše Nezvalová, CSc. (Palacký University in Olomouc)
dr. hab. Małgorzata Nodzyńska (Uniwersytet Pedagogiczny, Krakow, Poland)
prof. RNDr. Miroslav Papáček, CSc. (University of South Bohemia in České Budějovice)
RNDr. Lenka Pavlasová, Ph.D. (Charles University, Prague)
prof. RNDr. Ján Pišút, Dr.Sc. (Comenius University in Bratislava, Slovakia)
prof. Dr. Gorazd Planinšič, Ph.D. (University of Ljubljana, Slovenia)
RNDr. Vladimír Přívratský, CSc. (Charles University, Prague)
Prof. Bernard Sarrazy (Université Bordeaux, France)
dr. hab. prof. UR Ewa Swoboda (Uniwersytet Rzeszowski, Poland)
doc. RNDr. Jarmila Robová, CSc. (Charles University, Prague)
doc. Dr. Andrej Šorgo (University in Maribor, Slovenia)
doc. RNDr. Josef Trna, CSc. (Masaryk University in Brno)

Editorial Office
Charles University, Faculty of Education (Naďa Vondrová)
Magdalény Rettigové 4, 116 39 Praha 1, Czech Republic
e-mail: scied@pedf.cuni.cz

Typesetting in LaTeX done by Miloš Brejcha, Vydavatelský servis, Plzeň.
Logo design: Ivan Špirk.
Contributions in this Special Issue did not go through language editing.

Editor of this Special Issue: Leoš Dvořák