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Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning

Edited by Lars-Jochen Thoms and Raimund Girwidz



**Selected Papers from the
20th International Conference on
Multimedia in Physics Teaching and Learning**

**Selected Papers from the
20th International Conference on
Multimedia in Physics Teaching and Learning**

**September 9–11, 2015
at LMU Munich, Germany**

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Preface

We are delighted to publish the Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning (MPTL'20). This conference was held at the Ludwig-Maximilians-Universität München, Munich, Germany from September 9th to 11th, 2015.

MPTL conferences provide an international forum for the discussion of recent developments and advances and ensure that knowledge and experience in new methods and approaches are shared throughout the physics education community. Innovations as well as challenges for teaching and learning physics with modern media are discussed. Material for primary schools is included as well as topics for universities.

The scientific program of the 20th edition consisted of five plenary talks, 66 single talks and 25 posters. All of the proposals were reviewed, blind, by two or three reviewers from an international scientific advisory board. The meetings were organized in thematic symposia, parallel sessions, parallel talks, workshops and plenary sessions.

The conference provided insight into three main issues concerning the effective use of multimedia in teaching and learning physics:

- new hardware and software technologies,
- concepts for teaching and learning scenarios with innovative ideas, and finally
- empirical studies on important factors for learning with digital media and students' assessments.

In addition, 14 special teacher workshops on the use of modern media were offered.

The authors were asked to produce updated versions of their papers and take into account discussions that took place after the presentation and suggestions received from other participants at the conference. Overall, the proceedings present a comprehensive overview of ongoing studies in research on multimedia in physics education in Europe and beyond. This book represents the current areas of interests and emphasis in the MPTL community as of the end of 2015. The Proceedings contain ten parts that correspond, for instance, to invited symposia and thematic parallel sessions. All formats of presentation (plenary, symposium, workshop, single oral, poster) used during the conference were eligible to be submitted to the Proceedings. All submissions were reviewed a second time by at least two referees before being accepted for publication. Nevertheless, the authors are responsible for their contributions. All revised and accepted papers are collected in the electronic proceedings. Furthermore, reviewers were able to suggest excellent and inspiring articles for the book of selected papers. Hence, high ranked contributions are also available in a printed book version.

This conference was made possible thanks to the work, sponsorship and interest of many people and institutions. First, we want to thank the Ludwig-Maximilians-Universität München (LMU Munich) for hosting the events (plenary talks, invited symposia, parallel sessions, and poster sessions, among others). The LMU Munich provided some of its facilities in the form of assembly halls and lecture rooms, and provided monetary support to organize this conference. Second, we gratefully acknowledge the extraordinary support of MPTL'20 by the German Research Foundation (DFG). In addition to monetary support, we appreciate the recognition of MPTL'20 in the scientific community, even though we discuss very specialized topics. Equally important has been the support of the European Physical Society (EPS), the main sponsor of the MPTL conferences, year after year. Furthermore, we want to thank the German Physical Society (DPG), the Wilhelm und Else Heraeus-Stiftung, and the city of Munich for their support.

We owe a great debt of gratitude to the members of the Scientific Advisory Board, the International Program Committee, and the National Organizing Committee, the staff from the LMU Munich, and all other people who have contributed significantly to this conference.

Finally, yet importantly, thanks are also due to the well-known five plenary speakers Jochen Schieck, Michael Dubson, Christian Hackenberger, David Lowe, and Wouter van Joolingen as well as to all participants that attended MPTL'20. Without you, the conference would not have been possible.

We would like to thank all the authors that contributed their papers to this book and all the referees whose critical feedback helped to improve the quality of the content.

A handwritten signature in blue ink, reading "R. Girwidz".

Raimund Girwidz

A handwritten signature in blue ink, reading "Lars-Jochen Thoms".

Lars-Jochen Thoms

SIMULATIONS AND VISUAL REPRESENTATIONS IN PHYSICS EDUCATION

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Interactive Video Vignettes

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Interactive Video Vignettes (IVVs) are short web-based assignments for introductory science students. IVVs typically address learning difficulties identified by Physics Education Research (PER). Many of them make use of the classic *elicit-confront-resolve* (ECR) technique that has been used effectively in the design of many research-based curricular materials. In addition, they may include video analysis and graphing activities that allow for interactivity. IVVs are implemented as web applications that typically take about 10 minutes or less to complete. We also developed *Vignette Studio*, a Java application that allows anyone to easily create IVVs. The IVV team is currently developing new IVVs and analyzing them in terms of their student learning gains to determine best practices in creating future vignettes.

1 Introduction

Many video-based and web-based materials are already available for helping students learn physics. There are videos of lectures and demonstrations, virtual laboratory experiments, simulations and much more. What is harder to find are active video-based online materials that combine video narration with predictions, data collection and analysis, and other interactive elements. The Interactive Video Vignettes (IVV) project was created to develop and test such materials.

2 What is an IVV?

An IVV is a web application that combines video with interactive elements such as video analysis, graphing, multiple-choice questions, and question-based branching. The format includes a series of video segments that are interspersed with questions and other activity-based screens. A typical simple vignette might consist of an introductory video, some type of measurement and analysis, and a wrap-up video to conclude the lesson. A more complicated vignette might include several experiments or demonstrations with discussions of the theory.

Vignettes are implemented using JavaScript and HTML5, so they run on tablets as well as laptop or desktop computers. A vignette can be installed on a static webserver by simply copying its folder into the web directory. Installing vignettes on dynamic servers, such as online homework systems or Learning Management Systems, would require help from the information technology staff that maintain the system.

2.1 Projectile Motion Example

The Projectile Motion IVV deals with the independence of horizontal and vertical motion only. Although it is a simple concept, it is one that frequently confuses students. This vignette takes students about five to seven minutes to complete. A preview of it is available at the project website (www.compadre.org/ivv/).

Teese, R. B., Laws, P. W., & Koenig, K. (2016). Interactive Video Vignettes. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 11–16). Mulhouse: European Physical Society.

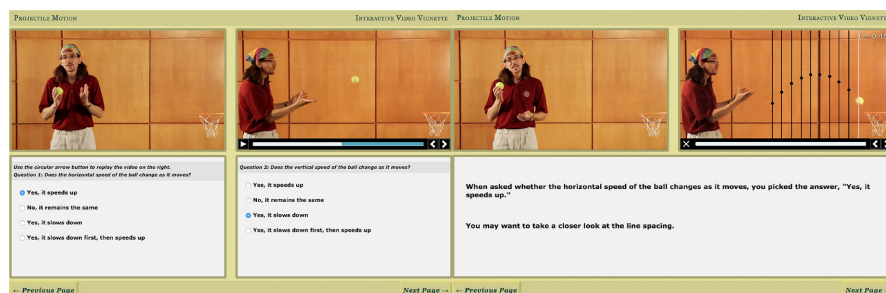


Fig. 1. Left: Two multiple-choice questions in the Projectile Motion vignette. Right: Results of video analysis, showing the student's prediction.

In the introduction, the narrator discusses some basic aspects of projectile motion. The discussion is illustrated with a dramatic shot of a person being thrown high into the air and landing in a lake. At the end of the introductory video, the narrator tosses a ball into a basket.

Next, students are able to replay the tossing of the ball into the basket as many times as they want. Meanwhile, the narrator asks the student to watch the tossed ball and focus on the horizontal motion separately from the vertical motion. Before moving on, the student must answer two multiple-choice questions about the horizontal and vertical motion of the tossed ball (is it speeding up? slowing down? etc.).

In the next segment, the horizontal motion of the ball is investigated using video analysis. Students click on the center of the tossed ball to mark the position of the ball in each frame of the video. After each click, the horizontal position of the ball is marked with a vertical line (Fig. 1). The narrator then asks the student to deduce something about the horizontal motion of the ball. On the following page, the video analysis results are shown along with the prediction the student made earlier. The narrator explains that since the time between video frames is constant, the equal spacing of the lines means the ball moved in the horizontal direction with constant speed. In the next segment, the process is repeated, with the student creating vertical lines and seeing that the ball slows down going upward and then speeds up going downward.

2.2 Elicit-Confront-Resolve

A typical IVV makes use of the classic *elicit-confront-resolve* (ECR) educational technique (McDermott, 1991): it *elicits* a prediction from the user, *confronts* the user with an experimental result, and helps the user *resolve* any differences between them. This technique is a very effective method that has been used in many research-based curricular materials, including Tutorials in Introductory Physics (McDermott, 1991) and Workshop Physics (Laws, 2011).

2.2.1 Newton's Third Law Vignette

In the Newton's Third Law vignette, we modified the resolve step described above to help students understand why many of them make incorrect predictions. This vignette shows person-on-the-street interviews about the forces on cars in a collision. Each interviewee watches a video on a tablet computer of two identical low-friction carts colliding (Fig. 2 left), and the interviewer asks them to predict the relative forces on each cart. All of the people predict that the carts experience equal forces. These predictions are tested when the people are shown a video of real-time force graphs being made while the carts collide. The sensor readings show that at each moment the forces on the carts are equal and opposite.



Fig. 2. Left: An interviewee watches a video of carts colliding. Right: The driver of the lighter cart falls on his face during the collision, even though the forces on the carts (seen in the graph) have the same magnitude.

Next the interviewees watch a short video of two automobiles colliding on a street. One car is larger and faster than the other. Most of the interviewees say that the larger, faster car exerts a larger force on the smaller, slower car than vice-versa. A multiple-choice question elicits a prediction from the student using the vignette. The interviewees, as well as the student watching the vignette, are then confronted with a video of the laboratory carts colliding, this time with an extra mass attached to one of them. A real-time force graph shows that the larger, faster cart experiences the same force at each moment as the lighter, slower cart. At this point, most students using the vignette will see that their prediction was wrong. To help them come to terms with this, the resolve stage was modified by adding a reflect stage. This is another elicit-confront sequence in which nearly all students will choose the correct answer. The interviewer asks, "Which car would you rather be driving?" The interviewees all choose the larger, faster car. The interviewer shows a video of the laboratory carts, but now each has a toy driver sitting on top. The one on the larger, faster cart barely slides during the collision but the driver of the smaller, slower cart falls on his face (Fig. 2 right). The interviewer describes how Newton's Second Law explains why the smaller cart has a larger acceleration even though the forces on the carts are equal and opposite.

2.3 Uses of Interactive Video Vignettes

IVVs are designed for use as online assignments such as homework, pre-lecture or pre-recitation tutorials, or "flipped-classroom" lecture segments. The interactivity helps engage students and keep them focused. Since many vignettes use the pedagogically effective elicit/confront/resolve strategy described above, it is important that the students feel free to choose answers that reflect what they really believe rather than what they think the instructor wants to hear. Consequently, vignettes should not be used as graded homework.

We did preliminary research to see what kinds of motivation students need to encourage them to finish a vignette. When students were told that a vignette would help them learn, or that the vignette would cover material that would be on an exam, less than 40% of the students completed the vignette. When they were told that completion would earn them a small amount of homework credit or exam credit, 87% of 1184 students completed the vignette. These results are consistent with findings at other institutions (Kontur, 2014) (Scharff, 2010).

To provide motivation for students to complete a vignette, we recommend that students receive a small amount of completion credit such as a few homework points, an extra point on an exam, etc. The vignettes posted on our ComPADRE website have pages at the end that show the name typed in by the student who began the vignette. This page can be printed out and submitted to the instructor as proof of completion.

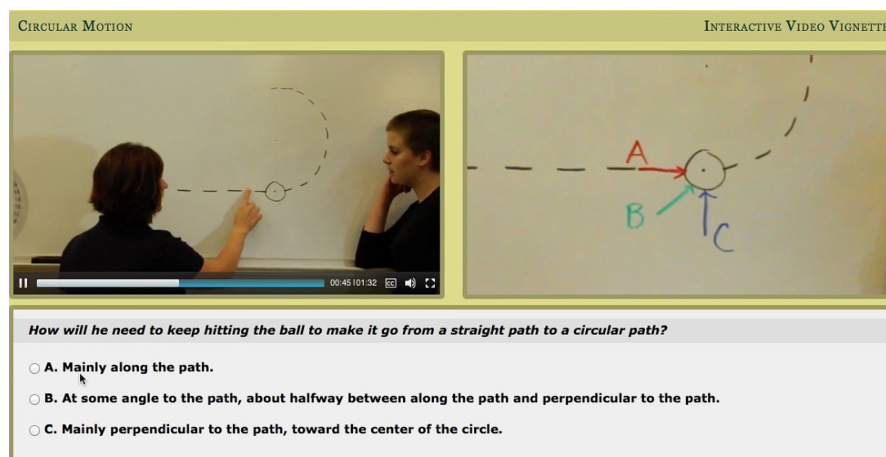


Fig. 3. The elicit stage of the Circular Motion vignette.

3 Products

The project team is creating a set of vignettes that illustrate various styles and teaching techniques. In addition to examples of using a single narrator (as in the Projectile Motion vignette) or person-on-the-street interviews (as in the Newton's Third Law vignette), the ComPADRE website has IVVs with an instructor interacting with one or more students, an instructor engaging in Socratic dialog with a group of students, and two instructors talking to each other. The topics covered include Newton's Laws, circular motion, conservation laws in an inelastic collision, and electrostatics. Other sample vignettes are in production. The goal is to help other people develop script ideas by creating and testing a collection that illustrates various ways of making vignettes.

Vignette Studio, a free, easy-to-use Java application being created by the project, allows instructors to make their own vignettes. Using its drag-and-drop interface, a developer moves pages into place on a workspace. Individual elements, such as images, videos, questions, video-analysis modules, graphs and so on can be dragged into place on each page. The user's input on one page can be echoed back on a different page, allowing users to compare their predictions to the results of experiments. Question-based branching can be set up, so that each answer to a multiple-choice question links to a different subsequent page. In this way vignettes can provide remediation that is specific to the user's needs. Additional software capabilities are planned for implementation in the remaining years of the project. The software and user manual can be downloaded from our ComPADRE website (<http://www.compadre.org/IVV/studio.cfm>).

Two related projects are also underway. First, at Bethel University, Keith Stein, Chad Hoyt and Nathan Lindquist are making pre-lab activities for use in advanced physics lab courses (US National Science Foundation awards 1245573 and 1245147). The topic areas include fluid mechanics, AMO (atomic, molecular, and optical) physics, plasmonics, and nano-optics. These researchers are using Vignette Studio to make the activities, and are helping to enhance the IVV software with the inclusion of new capabilities. For example, in one activity students will analyze high-speed and shadowgraph videos of a ping-pong cannon to study supersonic flow and shock waves.

Second, a team at RIT and Alfred University is authoring a set of interactive modules for introductory biology courses (US National Science Foundation awards 1432286 and 1432303). The online priming activity in each module is an IVV. So far, vignettes on osmosis, acid/base buffers, natural selection, fermentation, genetics, scientific graphing, and photosynthesis have been finished and are being tested in biology courses.

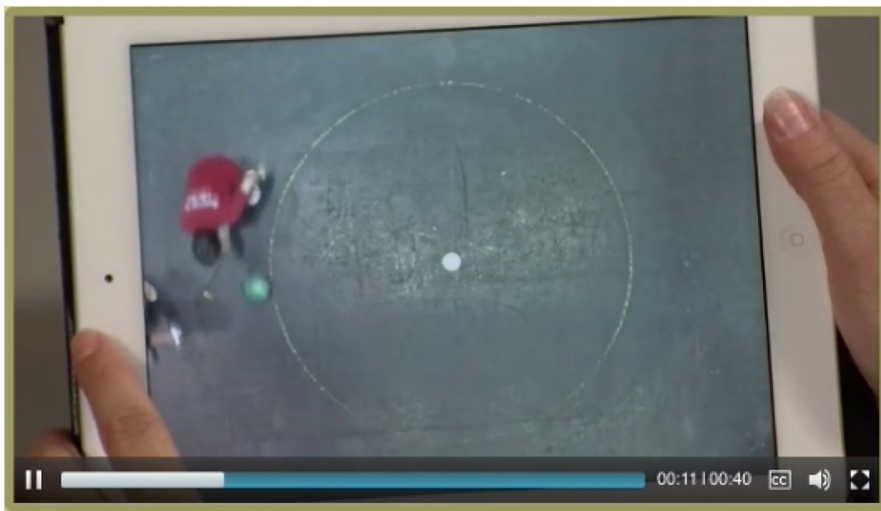


Fig. 4. The confront stage of the Circular Motion vignette. The instructor must tap the ball toward the center of the circle to make it follow a circular path..

4 Impact on Learning

Controlled studies are taking place at the University of Cincinnati to gauge the impact of Interactive Video Vignettes on student learning in physics. One study (Laws, 2011) involved three instructors across six sections of algebra- and calculus-based physics at the University of Cincinnati. Each instructor taught two sections of the same course during the same semester, using similar teaching approaches and materials. In one section the instructor assigned four IVVs (projectile motion and Newton's Laws), but in the other section ordinary homework was assigned instead. A pre/post test consisting of the Force Concept Inventory (Hestenes, 1992) plus five additional questions was given at the beginning and end of each course. The pre-test scores in both the treatment (321 students) and control (244 students) groups were similar. On the post-test question for projectile motion, 91% of students in the treatment group indicated that the horizontal speed of a projectile remains constant whereas only 79% of students in the control group made a similar correct choice. There was no significant difference between the treatment and control groups for the vertical speed question. For the Newton's Third Law vignette, an average of 66% of students in the treatment group correctly applied Newton's Third Law on questions about the collisions of objects with different masses compared to 49% in the control group. For the other two Newton's Law vignettes, the pre/post tests did not show significant gains. We have revised those vignettes and are continuing to study their effectiveness.

4.1 Study of the Circular Motion Vignette

This vignette is based on an experiment in which a person tries to make a rolling ball roll in a circle by tapping on the ball with a stick. The vignette shows an instructor talking to a student about the experiment. The first question (the elicit stage) is about how the ball should be tapped to make it roll in a circular path (Fig. 3).

In the confront stage, a video is shown of an instructor carrying out the experiment (Fig. 4). To make the ball roll in a circular path, the instructor must tap the ball toward the center of the circle. The resolve stage is a discussion between the student and instructor.

The pre/post question most relevant to this vignette is the Force Concept Inventory (FCI) question about a ball rolling in a frictionless circular channel on a tabletop. The question asks which forces act on the ball, and lists four possible forces: a downward force

due to gravity, a radially inward force exerted by the channel, a force in the direction of motion, and a radially outward force exerted by the channel. The correct answer choice is the force of gravity and a radial inward force. The treatment group shows a slightly larger gain overall than the control group, but one that is not significantly larger. However, we noticed an interesting effect when looking at the individual answer results. The number of students choosing the correct answer went from 18% on the pretest ($n=331$) to 42% on the posttest, which is a significant gain. At the same time, the number of students choosing a particular incorrect answer (the two correct forces plus a force in the direction of motion) increased from 29% to 34%.

Why did some of the students seem to learn the wrong thing? It appears that they were choosing an “impetus” force (a force in the direction of motion), suggesting they had not understood Newton’s First Law. Since the students had been assigned the Newton’s First Law vignette, we looked at the results from that vignette. We found that students who saw both the Newton’s First Law and Circular Motion vignettes went from 17% to 43% correct (a normalized gain of 31%) on the circular motion question. Students who saw the Circular Motion vignette but had not seen the Newton’s First Law vignette went from 21% to 37% correct (a normalized gain of 20%) on the circular motion question. That is to say, seeing the Newton’s First Law vignette before seeing the Circular Motion vignette seemed to have a positive influence on student performance for this circular motion question. This was observed even though we did not measure a significant gain on the Newton’s First Law vignette by itself. We are continuing to study the interaction of vignettes in combination and in isolation to try to understand this effect.

5 Conclusion

Interactive Video Vignettes offer a way to make online presentations that engage students with active involvement. Ongoing research shows that IVVs can have a significant positive effect on learning in physics. Both sample vignettes and Vignette Studio software, which allows instructors to create their own vignettes, are available at no cost on the project’s ComPADRE website (www.compadre.org/ivv/).

Acknowledgements

David Jackson, Patrick Cooney and Maxine Willis are senior personnel in the project. Dozens of students at RIT and Dickinson College helped write the software and make sample vignettes. The work is funded in part by the U.S. National Science Foundation grants 1123118 and 1122828.

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Ask the Simulation: Challenging Questions and Visual Answers for Project-Oriented Learning

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Encouraging science learners to generate questions is upheld as a valuable instructional practice. Responsive physics simulations sustain the generation of questions, and provide tools for discovering and presenting answers. Our study reports on a question-generation activity in the context of a project-oriented program for high school physics students. The students found online optics simulations, formulated questions about them, and presented answers visually. Approximately 900 questions and answers were submitted by 30 students in 2014-2015. Two analysis approaches were adopted: An analytical approach, which classified student products based on ten criteria, and an interpretive approach based on the relevance of the products to physics projects. We present some analytical results for a sample of 223 questions, and interpretive evidence about project-related knowledge such as tool-usage, development of comprehensive views of physical phenomena, exploration of alternatives, and the identification of similarities and purposeful design.

1 Introduction

Project-oriented science learning is considered a hallmark of effective science education. Implementing this instructional approach requires a shift from traditional instruction in the types of learning environments, the level of student independence and the types of dispositions towards learning that are promoted. The instructional approach of “*Science as inquiry*” and “*Science by Inquiry*” (Baybee, 2004) indicates the necessity to create and use responsive learning environments in which asking questions is encouraged and even required (Windschitl, 2000).

1.1 Generating Questions by Science Learners

Asking questions is a natural way of using language to obtain desired information. In the education system, students are frequently required to respond to questions formulated by teachers or contained in the learning material or in examinations. Students also generate their own questions, either spontaneously or when encouraged to do so by teachers. Question generation has been recognized as an important process in knowledge construction and integration. In formulating a question, learners use scientific concepts, reflect on newly-acquired knowledge, share curiosity and uncertainty with peers, and express readiness to extend their knowledge (Chiappetta, 1997; Chin & Brown, 2002; Chin & Kayalvizhi, 2002). Student-generated questions can serve as diagnostic indicators, as they reveal students’ level of understanding and possible misconceptions (Maskill & de Jesus, 1997). From the considerable body of research that has been conducted on question-generation by science learners, one of the results have been taxonomies of the types of question generated (Marbach-Ad & Sokolove, 2002; de Jesus, Almeida, Teixeira-Dias & Watts, 2007). In these studies, questions are classified as “*lower order*” or “*higher order*”, depending on the

Langley, D. V., & Arieli, R. (2016). Ask the Simulation: Challenging Questions and Visual Answers for Project-Oriented Learning. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 17–24). Mulhouse: European Physical Society.

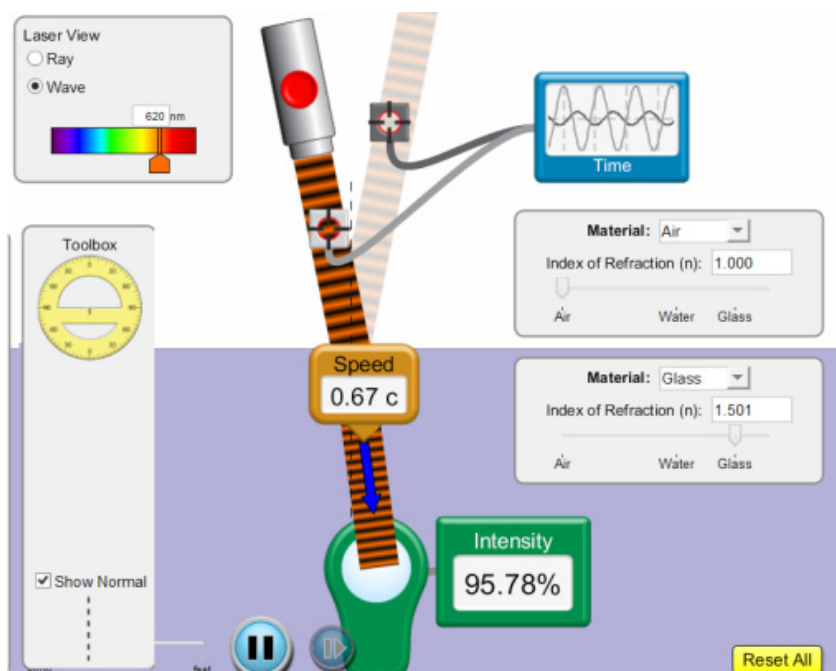


Fig. 1. Bending Light rich simulation screen.

process required to obtain an answer. Langley & Eylon (2006) defined 5 question types according to the knowledge students sought: system state, relation or pattern, technical information, design target and system mechanism.

In spite of the potential of question-generation for promoting learning, research has shown that the classroom setting offers students insufficient opportunity to exercise this skill (Kaya, 2015). This may be due to the pressure teachers feel to “cover the material”, the need to maintain discipline in large classrooms, or the disinclination of students to propose questions due to fear of embarrassment or lack of practice. The science laboratory seems a natural setting for question-generation by learners, in particular in the format of an inquiry/research question, thus promoting feelings of ownership toward the experiment or project (Hofstein, Navon, Kipnis & Mamlok-Naaman, 2005). However, science experiments are often presented to the students complete with the research question and measurement procedure – leaving little opportunity for autonomous question generation.

1.2 Simulations as Responsive Environments

Simulations are cognitive technologies that can facilitate the presentation, manipulation and exploration of rule-based models (Pea, 1987). Computer simulations have been part of physics education since the 1980s. Simulations can be employed for teaching and learning physics in a variety of methods (e.g. Girdwidz, 2007; Langley, 2010). Simulations vary in their richness of content knowledge and representation methods, and the tools they provide for exploring the modeled subject.

Redish (1993) indicated two features of visual “live” simulations that help students build correct and appropriate mental models: the effect of seeing a system change and the effect of user control. These features define interactive, responsive environments (Shedroff, 2000). Following advances in computer graphics and audio-visual effects, simulations provide compelling virtual reality environments in which students safely manipulate



Fig. 2. Students exploring wave simulations.

“physical” entities and experience the results through multi-modal representation (text and numbers, shapes, colors and sound) (Rutten, van Joolingen & van der Veen, 2012).

Rich responsive simulation environments can be expected to facilitate question-generation by students, due to the explicit “tangible” presence of “physical” entities such as position, mass, voltage, wave-length and mirror curvature. The more variables are included in the computational model, the closer the simulation behavior and appearance approximate reality. For example, if wave damping is included in the computational model of a vibrating string, then students will see the amplitude decrease as a pulse propagates along the string. If partial reflection is included in the computational model of a two-dimensional wave refraction model, then students will see both reflected and transmitted waves with appropriate intensities (fig. 1). These effects can be particularly useful for generating a 360° view of phenomena in the context of project-oriented learning. However, since the sophistication and realism achievable in physics simulations is always limited, and since the computational model often represents idealized situations, it is important to alert learners to possible discrepancies between the outputs of simulations and of real experiments.

2 The Study

The “*Physics & Industry*” program is a for-credit, 15 month, out-of-school framework fostering excellence and providing a link to science-based industries for high ability high school physics students. Participants design a working model dealing with a real world problem based on electro-optical principles (Langley, Eylon & Arieli, 2010). Simulations have been used extensively within the program since its inception in 2004. However, the “Ask the Simulation” activity was first introduced into the program in 2014 in an effort to encourage independent active learning, and to allow students with different physics backgrounds to proceed at their own pace and follow their chosen paths in class and later at home.

2.1 The “Ask the Simulation” Activity

The activity was given the motivational title “*Collecting information for the final project report*” and it included several stages: Searching for information sources about central concepts and principles related to the selected physics topic; Finding topic-related simulations; Formulating 20 questions to which the simulations could provide answers; and, finally, Presenting the answers visually as simulation screen shots. Students worked individually or in pairs for about 30 minutes (fig. 2), with the instructor providing advice and technical tips; they then completed the assignments at home.

2.2 Data Collection

We collected data from two separate groups over 2014 and 2015. Students responded enthusiastically to the activity, and were surprised by the large number of freely available

Year	Students	Refraction (st)	Waves (st)	Lenses (st)
2014	25	227 (12)	328 (19)	NA
2015	20	160 (8)	114 (6)	70 (4)

Tab. 1. Number of questions per topic per year.

Rubric	Value	Key words	Examples
1	Description, Demonstration, Explanation	What happens? Does the ...? What is....?	Does refraction occur when both materials have equal refractive indices? What is the wave's amplitude?
2	Seeking mechanism	Why,	Why does the intensity of the refracted ray increase when the index of refraction increases?
3	Designing, Engineering	How? When?	Is there a situation where the intensities of the reflected and refracted rays are equal?
4	Relationship, Inquiry	Depends on	How does damping affect the amplitude?
5	Calculation, Explain calculation	What is the "quantitative concept"? How much?	What is the angle of refraction between air and glass, for a 60° angle of incidence?
6	Verification, Analyzing simulation behavior,		Does the glass absorb light?

Tab. 2. Rubric for the Purpose criterion: values, key works and examples.

simulations dealing with optics and waves. Most of the students eventually produced and submitted 20 questions and answers, sometimes in pairs (tab. 1). The number of students who had submitted questions at the time the analysis was performed is the parentheses. We detected some instances of shared or duplicated questions.

2.3 Research Questions

1. What types of questions were generated?
2. What consequences did the activity have regarding project-oriented learning?

2.4 Data Analysis and Results

The collected questions and answers were analyzed using two approaches – an analytical approach and an interpretive approach.

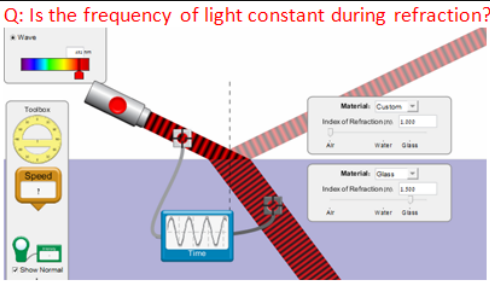
2.4.1 Analytical Approach

A set of 10 criteria was defined for the analytical approach: 1. Content; 2. Formulation; 3. Purpose; 4. Complexity; 5. Concepts; 6. Originality; 7. Tools; 8. Answer format; 9. Answer reasoning; 10. Answer accuracy. After coding a sample of question and answers, each criterion was given several descriptive, non-content-related values – thus creating a rubric for analyzing future questions. In order to reliably assign values to each criterion, an additional rubric was created, containing key words and specific examples for each value (tab. 2).

An Excel spreadsheet was created for collecting the analysis data for each topic and student group (e.g. Refraction 2014). Each data group forms a matrix of 200 rows and 10-20 columns (depending on the number of students). When the analysis is concluded there will be 5 such data groups.

Owing to the considerable time required for the detailed analysis of some 900 questions,

Q: Is the frequency of light constant during refraction?



A: Yes.The simulation allows us to compare the frequencies of the incident and refracted rays (light and dark gray). It is easy to see that the frequencies are equal. The frequency does not change during refraction.

Content	light waves 2D
Formulation	accurate
Purpose	Inquiry
Complexity	complex
Concepts	advanced
Originality	non-standard
Tools	advanced
Answer format	visual + verbal
Answer reasoning	simulation output
Answer accuracy	accurate

Fig. 3. Analytical approach example.

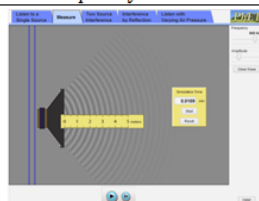

this process has yet to be completed. Fig. 3 shows an example of the analytical approach. To date we offer results for 223 questions, submitted by 17 students in the 2014 group. The questions were generated using the PhET simulations (<https://phet.colorado.edu/en/simulations>): “Waves on a String” and “Bending Light” (presenting water, sound and light waves).

Analysis of the content topics shows a selection of sound waves (24%), pulses, and waves on a string (27%), water and light waves (12% each) and transmission and interference (11%). Analysis of the question purpose shows two main trends: description (52%) and inquiry (41%). Analysis of the simulation set-up shows that over half the questions used advanced (46%) and complex (15%) set-ups including multiple phenomena and/or several measurement tools. We intend to continue the analysis of the collected questions and publish our findings in the future.

2.4.2 Interpretive Approach

Asking questions and seeking answers in responsive environments, such as rich simulations, can be framed as a learning experience with special opportunities for developing skills and insight related to physical phenomena. In the particular context of project-oriented learning, we sought evidence for types of behavior that were compatible with designing and carrying out a project, rather than conventional school work such as solving textbook problems.

Using Tools

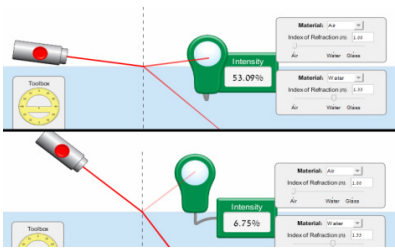
<p>Q: How much time will it take a sound wave of 800Hz frequency to cross 5 meters?</p> 	<p>Q: Does tension affect the wave's speed?</p> 
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This type of question indicates a disposition towards using technological tools for discovering answers to questions. This disposition is important for executing a project.

Gaining a Comprehensive View

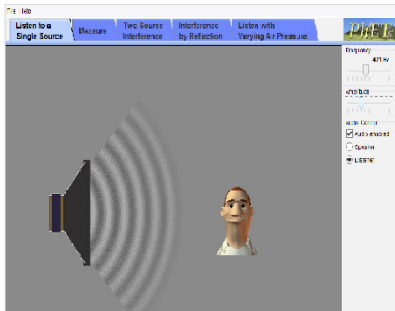
Q: Does the intensity of the reflected light depend on the angle of incidence?

This aspect of refraction, often overlooked in classroom physics, is important for the design of optical systems. The simulation affords the learner an opportunity to experience this phenomenon both visually (by the color intensity of the partially reflected light) and quantitatively (by using the intensity meter). Implementing this feature in an optical system requires using an appropriate detector, such as a voltaic cell.



Q: Does sound reach the listener instantly?

By selecting the listener as the audio detector, and changing the volume of the source from zero to a certain level, the student can experience the time lag between the sound source activation and the sound detection by the listener. It is important to note that in reality one rarely experiences this signal lag, except when hearing an echo.



Recognizing Similarities

Q: Does the wave intensity decrease with distance?
Comparing water, sound & light waves

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Physics lessons tend to compartmentalize physics knowledge, instead of pointing to similarities. This type of question points to an integrated concept of wave phenomena.

Exploring Alternatives

Q: Does one source and two slits behave like two sources?

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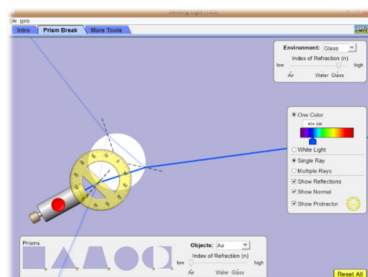
In designing a technological system one may need to find an alternative for an intended

component. Testing the functional equivalence of the alternatives is a vital engineering requirement.

Engineering an Outcome

Q: What is the incidence angle of light passing from glass to a sphere of air that will yield refracted and reflected rays in the shape of an equilateral triangle, as inscribed in the sphere?

This unique question indicates a design attitude, highly useful for carrying out a project. The student uses the available components to create a desired outcome.

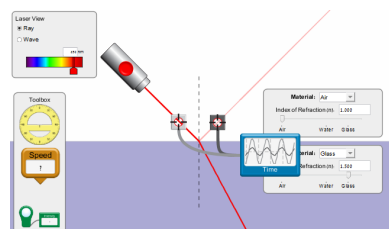


Problematic Issues

Simulations are driven by computational models which may be idealized or may have limited accuracy. Likewise, simulations may offer simplistic representations of measurements which are very difficult, or even impossible, to perform in reality.

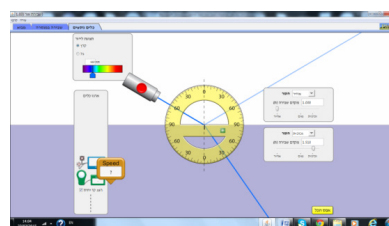
Q: Is the frequency of incident light equal to the frequency of the reflected light?

This is a valuable question, in which the student related the visible feature of light color with the invisible feature of light wave frequency. However, the simulation creates the impression that one can use an “oscilloscope” to trace light waves, and simply view their amplitude, frequency and phase. This is misleading, and fails to address the issue of the order of magnitude of visible light frequency. Likewise, reflected light has a different phase than the incident light.



Q: Does the color of light affect the angles of incidence, reflection and refraction?

This is a poorly formulated question, since the angle of incidence is an independent variable. However, the real problem is that the student concluded that the angle of refraction was not affected by the color due to the inadequate sensitivity of their measurements. The simulation did vary the refractive index when different colors were selected, but the change in the angle of refraction was negligible, relative to the sensitivity of the compass. A digital output, with sufficient accuracy, would have prevented this flawed conclusion.



3 Conclusions and Implications

Current education policy includes a requirement for project-oriented science learning at the k-12 levels and beyond. The shift from traditional, teacher-controlled instruction to project-oriented learning entails many changes and presents considerable challenges. Promoting student inclination and competency in generating questions is an important step in the adaptation process. The current study indicates that rich physics simulations provide learning environments in which students can practice important skills. These include generating questions of varying complexity, manipulating simulation variables and using

the dynamic output and available tools to arrive at a conclusion. This activity serves to substantiate student physics knowledge and leads to a more comprehensive view of real physics.

Our study also indicates that timely teacher supervision and feedback are vital, since students need guidance in formulating valuable inquiry and design questions and because computational models controlling the simulations may contain idealization or limited accuracy – leading to misrepresentation of physical reality.

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VIRTUAL AND REMOTE LABS IN PRACTICE

Marcus Brodeur, Nicholas Braithwaite, Ulrich Kolb and Shailey Minocha

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Improving Undergraduate Engagement with Online Labs: Student Priorities and Strategies for Virtual and Remote Investigations

Marcus Brodeur, Nicholas Braithwaite, Ulrich Kolb and Shailey Minocha
The Open University, UK

A large-scale study of undergraduates in five scientific disciplines was undertaken at the Open University in the UK. All cohorts made extensive use of virtual and remote experiments. Multi-stage surveys (with Likert-type, ranking and open-ended questions) elicited feedback on their experiences with this approach to practical science instruction. Universal themes about online labs (OLs) were identified and correlated against student performance on related assessments. Subsequent end-of-module group interviews confirmed student rationales and priorities for OLs. This study sought to discern the extent to which key aspects of computer-mediated practical work—*authenticity*, *sociability*, and *metafunctionality*—influenced students' ability to successfully engage with OLs. It was found that undergraduates value professional relevance and data reliability over photorealism and crave greatly expanded provisions for social modes of learning. Moreover, the students were found to value troubleshooting scenarios over sensory augmentation.

1 Introduction

Considerable previous work (de Jong & Njoo, 1992; Jimoyiannis & Komis, 2001; Finkelstein *et al.*, 2005; Zacharia *et al.*, 2008) has shown that typical "on-site" practical science (PS) is more effective when preceded by online experiments (OEs). Some research has even suggested that equivalent or superior learning outcomes result when students conduct an experiment virtually (Martínez-Jiménez *et al.*, 2011) or remotely (Corter *et al.*, 2004), rather than from the same physical location as real-world laboratory equipment.

Seldom addressed in the literature, however, are the underlying reasons *why* certain OEs succeed where others fail, or why *similar* OEs achieve better results with one cohort of undergraduates than with another. The position taken in this paper is that *students' perceptions* of computer-mediated practical science instruction—including the expectations and learning preferences they bring to their studies—determine how deeply they engage with OEs. This echoes earlier observations (Fraser & Walberg, 1991) that students learn better when exposed to environments and tools which support their pre-existing priorities.

Prior research in this area has highlighted a number of contributing themes which likely influence how students perceive and interact with remote experiments (REs)—i.e., where they obtain control over a distant, real-world device—and virtual experiments (VEs)—i.e., ones in which the procedure is conducted entirely within computer software. Our study examined how three elements in particular impact undergraduate success with such online investigations: *authenticity*, *sociability*, and *metafunctionality*.

Authenticity is the quality of a constructed learning experience that ensures students view it as realistic, relevant, and reliable. *Sociability* encompasses all aspects of interpersonal interactions in online practical work, especially the promotion of scientific collabora-

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tion and the accommodation of solitary learners. *Metafunctionality* refers to unique control and/or response features that would be difficult or impossible to implement in an on-site laboratory setting, but which are made possible by computer mediation of experiments.

2 Methods

A mixed-methods approach was employed for this study in order to secure the benefits of triangulation between quantitative and qualitative measures (Greene & Caracelli, 1997). Initial multi-stage survey instruments were followed by semi-structured interviews.

2.1 Participants

Participants were students at the Open University (OU), one of the world's largest distance learning institutions. Unlike in a traditional university, OU undergraduates are not based on a physical campus; rather, they engage with coursework entirely online, connecting via asynchronous (e.g., forums, wikis) or synchronous (e.g., Skype) communication media. Students pursuing a B.Sc. degree must complete the equivalent of 3 years of coursework, so undergraduate OU modules are divided by presumptive year into three levels of increasing difficulty: level 1 covering the most general material and level 3 the most advanced.

2.2 Sample Details

The sample included level-2 students taking five variants of the module "Practical Science" (S288); these consisted of chemistry & analysis (SXC288), environmental science (SXE288), geology & Earth science (SXG288), health & life science (SXHL288), and physics & astronomy (SXP288). It also included level-3 students taking "Astrophysics" (S382). These modules ran concurrently for 8 months from February to October 2014, over which time the count of unique respondents from each cohort numbered 152 (SXC), 196 (SXE), 216 (SXG), 244 (SXHL), 171 (SXP), and 169 (S382). However, 8 students opted out of the analysis phase, leaving a total of 1140 participants.

2.3 Online Experiments Encountered by Participants

The level-2 modules were structured around 4 study blocks ("*Topics*") specifically tailored to each scientific discipline. The majority of these involved between 1 and 5 selections from a menu of 22 virtual experiments (VEs). Several *Topics* additionally featured 1 of 3 remote experiments (REs): a biochemical oxygen demand (BOD) laboratory setup, a Compton X-ray scattering device, and a robotic telescope owned and operated by the OU ("PIRATE").¹

The level-3 module offered 3 study blocks, the first and last of which were textbook-driven. The middle third comprised a collaborative 11-week *Astrophysical Data Analysis Project*. One subset of the cohort planned and executed 6-7 full-night observing runs via live remote control of the PIRATE robotic telescope, then performed data reduction and analysis to prepare a light curve for a periodic variable star. Groups in the other subset selected and processed archival data from the Sloan Digital Sky Survey (SDSS) in order to produce a composite quasi-stellar object spectrum and characterise its key emission lines.

2.4 Staged Surveys

The survey instruments deployed in this study consisted primarily of sets of 5-point Likert-type sentiments (e.g., 1 = "strongly disagree", 3 = "neutral", 5 = "strongly agree") and ranking queries (e.g., "place these items in order of increasing importance to you"), supplemented by a handful of multiple choice and open-ended questions.

Level-2 students were polled at 6 points during the year: at the very start of their module ("Initial"), immediately after their engagement with each of the 4 *Topics* ("Post-Topic #"), and at the module's end ("Final"). By contrast, level-3 students were only surveyed at 2 points: immediately before they began their central *Project* ("Pre-Project") and im-

1 <http://pirate.open.ac.uk>

mediately afterward (“Post-Project”). In all cases, the surveys were made available to the undergraduates directly from each module’s VLE (virtual learning environment).

At both levels of study, the survey instruments were designed to ensure as high a degree of parallelism as possible in the question sets, in order to facilitate later comparisons of student responses from each cohort. This also involved the inclusion of matched pre/post items on both the “Initial” (S288) and “Pre-Project” (S382) and “Final” (S288) and “Post-Project” (S382) questionnaires.

During the pre-engagement stage, respondents were asked about their prior exposure to science, preferred science learning methods, and anxieties over practical work. Respondents were also asked about their expectations for skills improvement, opinions regarding the value of practical science, and intuitions concerning the use of online laboratories compared to traditional (i.e., on-site) labs.

During the post-engagement stage, respondents were asked how much the module had improved their skills or lowered their anxieties over practical work. They were also asked again about their preferred science learning methods and opinions of practical science and were requested to rate sentiments regarding the authenticity, sociability, and meta-functionality of remote and virtual experiments before ranking their final priorities for RE and VE design.

2.5 Group Interviews

At the conclusion of each module, undergraduates who were still registered were invited by email to participate in a series of interviews that were conducted over the month of October 2014. In total, 43 undergraduates took part in 17 semi-structured individual and group sessions. Primarily carried out via Skype, these interviews were subsequently transcribed and the responses from each participant tagged with demographic data before being anonymised.

2.6 Quantitative Analysis

Demographic data (e.g., age, domicile, gender) and assessment scores were obtained for all participants via the university records system and were entered along with all survey responses into a statistical software package (SPSS 22). Student *t*-tests were run to identify significant differences in attitudes and performance between each dichotomous subset of the study sample (e.g., gender, study level, *Project* choice). One-way analysis of variance (ANOVA) was also used across the five scientific disciplines featured in the level-2 modules. Paired-samples of *t*-tests were conducted on the matched individual responses from the pre- and post-engagement survey stages. Additionally, bivariate correlations were run between student age, Likert-type sentiments, and assessment scores for each subset.

2.7 Qualitative Analysis

The transcribed interview sessions and open-ended survey responses were entered into a qualitative data analysis package (NVivo 10). A word frequency analysis was conducted on the entire textual corpus to determine the words most often used by students in describing online laboratories. This analysis was also used to identify whether significant differences existed between the language used by those studying different scientific disciplines. Individual comments were subsequently coded according to a series of 43 lexical categories relating to undergraduate perceptions of online labs—e.g., *Disappointment/Frustration*, *Environment/Surroundings*, *Preparation/Training*. This formed the basis of a deductive thematic analysis in which the roles of authenticity, sociability, and metafunctionality in computer-mediated practical science instruction were more clearly defined.

3 Results

Key quantitative and qualitative results are presented below.

3.1 Quantitative Findings

Direct comparisons between more- and less-experienced (i.e., level-3 and level-2) students revealed a number of statistically-significant differences in their survey responses. These are summarised below, followed by positive/negative correlations observed between specific attitudes towards online labs and undergraduate academic outcomes. Overall pre/post-engagement shifts in student opinion for the six cohorts under observation are also shown.

3.1.1 Level of Study

At the *pre-engagement* stage, level-2 students were *more likely* than their level-3 peers to prefer investigation-led learning ($t(854)=5.738, p=.000$) and to agree that practical science (PS) is more enjoyable than studying theory alone ($t(854)=2.176, p=.030$). They exhibited *higher expectations* for their improvement in science skills over the module ($t(854)=2.121-5.743, p=.000-.034$), felt *more strongly* that PS experience would be valued by their future employers ($t(221.1)^2=3.934, p=.000$) and felt *more strongly* that PS should focus mostly on teaching lab techniques ($t(854)=4.317, p=.000$).

Level-2 students felt *more strongly* that PS requires on-site presence ($t(854)=4.317, p=.000$). They also agreed more that OEs lacked realism ($t(854)=3.195, p=.001$), relevance ($t(267.4)^3=7.479, p=.000$), and reliability ($t(255.3)^4=7.516, p=.000$) relative to proximal labs. By contrast, level-2 students were *less likely* than level-3 students to express anxieties over PS group work ($t(854)=-4.101, p=.000$) or to value PS for giving them access to “messy” real-world data ($t(854)=-4.164, p=.000$).

At the *post-engagement* stage, level-2 students reported a *greater preference* for instructor-led ($t(349)=2.075, p=.039$) and investigation-led ($t(349)=4.000, p=.000$) learning methods than those at level 3, as well as *less desire* for data-led ($t(349)=-3.689, p=.000$) and self-led ($t(349)=-3.241, p=.001$) methods. They also felt that their skills had improved more over the course of the module ($t(349)=1.993-5.977, p=.000-.047$) than did the level-3 students.

Again at the post-engagement stage, level-2 students agreed *more readily* that PS requires on-site presence for full effect ($t(204.9)^5=8.379, p=.000$), and that VEs are unrealistic ($t(349)=6.217$), irrelevant ($t(349)=4.124$), unreliable ($t(349)=3.814$), and ineffective for collaboration ($t(349)=3.594$) [all $p=.000$]. Likewise, they were *more likely* than level-3 students to find REs unrealistic ($t(349)=3.229, p=.001$), irrelevant ($t(349)=2.983, p=.003$), and unreliable ($t(266.6)^6=2.904, p=.004$).

When asked to rank design priorities for OEs, level-2 students were *less likely* to value expanded provisions for collaborative learning in VEs ($t(349)=-3.700, p=.000$) or REs ($t(349)=-2.531, p=.012$), or optional VE troubleshooting scenarios ($t(349)=-2.128, p=.034$). By contrast, they were *more likely* to prioritise simplified interfaces in REs than level-3 students ($t(349)=2.034, p=.043$).

3.1.2 Attitudes Correlating with Better Outcomes

Higher scores were noted for those who at the *pre-engagement* stage ($n=791-856$) agreed *more strongly* that PS is worthwhile because it provides “messy” real-world data ($r=.115-.131, p=.000-.001$) and because it is valued by future employers ($r=.084-.100, p=.003-.018$). Better outcomes were also observed for those who at the *post-engagement* stage ($n=350-351$) agreed *more strongly* that VEs ($r=.123-.142, p=.008-.021$) and REs ($r=.115-$

2 Degrees of freedom reduced to 221.1, as Levene’s test yielded $F(854)=5.269, p=.022$.

3 Degrees of freedom reduced to 267.4, as Levene’s test yielded $F(854)=11.765, p=.001$.

4 Degrees of freedom reduced to 255.3, as Levene’s test yielded $F(854)=10.241, p=.001$.

5 Degrees of freedom reduced to 204.9, as Levene’s test yielded $F(349)=8.365, p=.004$.

6 Degrees of freedom reduced to 266.6, as Levene’s test yielded $F(349)=5.073, p=.025$.

.176, $p=.001-.031$) accommodate the needs of solitary learners, that VEs ($r=.123-.177$, $p=.001-.021$) and REs ($r=.171-.178$, $p=.001$) make practical work easier to carry out, and that VEs ($r=.117-.206$, $p=.000-.029$) and REs ($r=.155-.224$, $p=.000-.004$) increase the reach of limited scientific resources. Among these respondents, stronger-performing students placed *higher priority* on realistic interfaces in VEs ($r=.119-.127$, $p=.017-.026$) and REs ($r=.114$, $p=.033$), and on the availability of accurate data in VEs ($r=.127-.174$, $p=.001-.017$).

3.1.3 Attitudes Correlating with Worse Outcomes

Worse assessment scores were observed for students who at the *pre-engagement* stage ($n=791-856$) reported greater anxiety about the time pressures of PS work ($r=-.103-.122$, $p=.001-.004$). At the *post-engagement* stage ($n=350-351$), undergraduates tended to perform more poorly when they felt VEs should prioritise simplified interfaces ($r=-.125-.175$, $p=.001-.020$) and supplemental sensory modes ($r=-.145-.182$, $p=.001-.007$).

3.1.4 Opinion Shifts Concerning Online Experiments

Opinions of VEs and REs improved after students engaged with them in their studies. Much *greater agreement* was observed on the post-engagement questionnaires that VEs ($t(296)=13.362$) and REs ($t(296)=13.098$) reduce physical risks to participants, that VEs ($t(296)=4.125$) and REs ($t(296)=5.889$) make PS easier to carry out, and that VEs ($t(296)=3.694$) and REs ($t(296)=4.095$) accommodate solitary learners. Moreover, after engagement students felt *more strongly* that REs improve the reach of limited resources ($t(296)=3.913$) and make PS more enjoyable to do ($t(296)=3.685$) [all $p=.000$].

Similarly, students showed much *less agreement* on the post-engagement questionnaires that VEs ($t(296)=-8.115$) and REs ($t(296)=-9.032$) don't teach collaboration well, that VEs ($t(296)=-5.889$) and REs ($t(296)=-7.862$) fail to give a feeling of "being there" at a scientific site, and that VEs ($t(296)=-2.805$) and REs ($t(296)=-6.245$) lack realism [all $p=.000-.005$]. Nonetheless, impressions of RE irrelevance ($t(296)=2.596$), VE irrelevance ($t(296)=5.521$) and VE unreliability ($t(296)=2.530$) all worsened after exposure.

3.2 Qualitative Findings

Over the course of the module-end interviews, several key themes in student perceptions of online labs were confirmed. Characteristic comments or quotations (*italicised*) are included below, identified by anonymised respondent IDs.

3.2.1 Students Feel That a Little Realism Goes a Long Way

The vast majority of respondents felt that "*things would be better less realistic and having more data to play with*" (rap936), with one noting, "*If you see inside a cockpit of an aircraft, you'll see tonnes of buttons and I have no idea what any of them do, and yet I can quite happily go on my PlayStation and fly a plane in there*" (daa957). Many others agreed that including "fancy graphics" in VEs where they were not needed "*felt gimmicky*" (kaj132).

3.2.2 Students Have Little Patience for IT Issues in Online Labs

Often VEs were compared with badly-designed computer games: "*It was like playing The Hobbit, where you had to follow an exact series of moves in order to get the expected result*" (rap936); and "*It was a case of guessing which order you needed to click various buttons that were hidden somewhere on the screen*" (pgb432).

3.2.3 Students Desire the Freedom to Make Genuine Mistakes

Students were frustrated when OEs forced them to perform a procedure in only one way, with no deviations from a linear course of action: "*[VEs] don't really give you an opportunity to understand how it works when you can't see it go wrong*" (bbm836). "*Making mistakes is an important part of your learning and you need a safe environment in which to do that*" (kbl654), preferably "*at uni and not during your first week with a new employer!*" (saa326).

3.2.4 Students Need Reassurance That Online Labs Are Relevant to Future Work

Many respondents worried that employers might consider RE work insufficiently “hands-on” (wbm614) and noted REs did not convey an impression of the remote site or the immediate vicinity of the instrument (wbi103). Some also doubted VEs could even teach real-world techniques: “*All the virtual experiments in the world aren’t going to prepare you for even the most basic wet chemistry tasks*” (ebm288); and “*I was grasping throughout for the actual reason I was supposed to be doing things in that particular way*” (cae567).

3.2.5 Students Crave Access to “Messy” Real-World Data

Many students noted that “*online experiments don’t give you a general appreciation for how messy real-world data is*” (tbn806). Nevertheless, some students recognised the value of models and simulations despite craving realistic data: “*Idealised models [are] a way of understanding the theory. And the messy data... you can only understand mess in the context of order*” (hbs903).

3.2.6 Students Long for Improved Social Learning Provisions

Concerns were expressed by the students over the absence of synchronous communication in most VEs and how this exacerbated feelings of isolation (eyl367), with some feeling an optional “*multi-user environment*” would remedy this (kjp622). For REs streamed in a “one-to-many” mode, students lamented having no way to carry out live discussions with their peers regarding the experiment (hxa074). Less-experienced students were concerned about the lack of expert assistance and felt REs should provide a lab technician to answer questions as they occurred to them (cya043). However, a minority of respondents, some identifying as on the autistic spectrum, praised current-model REs for allowing them to participate in group or partnered lab activities that might feel overwhelming if attempted face-to-face (hbs903).

3.2.7 Students Want to Experience Setup and Tear-Down Stages

Most respondents felt a major failing of REs was the fact that the experiment had already been set up by someone else: “*I don’t know if this genuinely counts as an experiment because there was someone in the lab making all of the preparations*” (tbn806). “*I just felt I was clicking on the video and getting the numbers and just going out again. I didn’t really get any feel for how I’d do that in a lab or why*” (jps012). Many also wished for video clips demonstrating sample acquisition (ecc607) and preparation (kbp078) stages.

3.2.8 Students Are Divided on the Benefits of Troubleshooting Modes

More-experienced respondents sometimes suggested VEs include non-ideal scenarios—“*To see if you remember to clean the cuvettes after handling them, you could alter the absorbance readings if you’ve left fingerprints on them*” (sxf906)—but most felt “*there’s a real danger of confusing students because it’s hard to tell whether the results you’re getting are because you’ve done something wrong or because the software is doing something wrong*” (kbp078).

4 Discussion

Whilst this study did find differences in OE perceptions by undergraduates at different study levels, it also identified attitudes towards (and design priorities for) computer-mediated practical work that consistently correlated with better or worse academic outcomes.

4.2.1 Authenticity

Although in the surveys students almost universally voiced a desire for more “realism” in VEs, the interviews revealed that they generally did not intend this to mean *photorealism*. Once a minimum threshold of visual fidelity is achieved, further efforts to recreate the exact controls of a real-world analogue are viewed as undesirable by students—echoing

Lindsay *et al.*'s (2009) distinction between “establishment reality” and “maintenance reality”. Instead, they felt VEs were far more likely to feel “fake” when students were prevented from making mistakes with consequences they could learn from. Also, whilst participants felt that the provision of at least one low-latency webcam view of the remote device was essential for making REs feel authentic, no consensus was reached as to whether additional sensory feeds (video or otherwise) would actually improve the experience.

Participants also strongly associated authenticity in OEs with “relevance”, although this had different connotations for different disciplines. Physicists felt online labs should prepare them to diagnose problems with experimental setups and handle uncertainties generated by instruments. Biologists and chemists prioritised familiarisation with real-world lab spaces and training with techniques and equipment they expected to use in employment.

Respondents furthermore insisted that data be “reliable”, most opining that VEs that do not incorporate real-world data were akin to glorified computer games. More-experienced students wanted greater control over instrument modes in REs and over experimental variables in VEs, whilst less-experienced students were more interested in heightening the sense of presence in REs and improving on-screen help systems in VEs.

4.2.2 Sociability

Students who valued sociability—and those more confident in the ability of OEs to offer social modes of learning—tended to perform better academically. Respondents generally found single-user VEs to be far too *isolating*—noting that they lead to feelings of frustration and helplessness when things went wrong during online labs. Consequently, they craved the provision of an optional “live chat” feature to let them connect with others accessing the same VE. By contrast, the majority of participants agreed that carrying out joint REs via Skype or similar voice-over-internet tools successfully fostered collaboration skills, although they did feel that group formation and teambuilding needed to occur *prior to the actual experiment*.

Less-experienced students seemed to place lower value on peer input, focusing on a need for “on call” experts to resolve key questions as they occur. By contrast, more-experienced students were less interested in instructor-led approaches and instead seemed driven by a desire to expand the feeling of “being there” at a scientific site amongst fellow students.

4.2.3 Metafunctionality

Undergraduates evinced little interest in most proposed forms of metafunctionality. They felt that VE enhancements like altering spatial or temporal scales, saving or restoring system states, or visualising or combining the results of multiple experimental runs—while potentially helpful—would see little practical use due to the time constraints of most university curricula. They were likewise unsure how valuable augmenting RE live video feeds with data overlays would be to their skill acquisition or understanding.

Less-experienced students felt that it would be far more valuable for OEs to give them practice with the setup and tear-down stages of experiments, and to help contextualise individual techniques or procedures within a larger investigation. However, they did not share the desire expressed by their more-experienced peers to be challenged with non-ideal scenarios that would give them practice with troubleshooting experimental problems.

5 Conclusion

The findings of this study lay out several key recommendations for the designers of online laboratories. Student priorities for VEs and REs were broadly aligned, with the greatest emphasis placed upon *achieving a sense of realism* in the interface and associated activities, followed by ensuring accurate data, responsive connections, and easy-to-control interfaces.

Although a few respondents did express a desire for more *visual* fidelity in online labs, most felt that realism in OEs would be better achieved by granting students greater agency, especially the chance to make (and learn from the consequences of) genuine mistakes. Perceived relevance was also an important factor in securing student engagement with VEs (and to a lesser extent, REs). Most participants felt that online labs should concentrate not on improving their conceptual understanding, but on familiarising them with laboratory settings, procedures, and instruments they would likely encounter in future employment, and wanted these presented in the greater context of “joined-up” scientific investigations. Additionally, undergraduates typically did not accept VEs as worthwhile practical activities unless they featured reliable, real—as opposed to modelled or computer-generated—data.

Most students also keenly desired greater provisions for *sociability*. VEs should facilitate social awareness and peer learning modes (e.g., chat windows to link several simultaneous users), albeit with the option to disable these if necessary to accommodate solitary learners. Study participants strongly valued collaboration in REs and felt that finding ways of maintaining a sense of shared presence with their peers was essential during live remote experiments. Less-experienced students also had greater expectations for assistance during OEs, either in the form of dynamic on-screen help or (ideally) live advice from experts.

Metafunctional elements were rarely valued (or used) by students in this study and should not be implemented by designers merely because the technology exists, as undergraduates often perceive them as “gimmicks”. However, there does appear to be future scope for providing students with apparatus setup and troubleshooting modes, as long as these are explicitly incorporated within the instructional design of their practical work.

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Implementing Different Learning Goals in an Online Experiment

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Experiments are an important part of Physics classes. Teachers pursue different learning goals when using experiments, but these goals are often limited when an experiment can be performed only as a demonstration. We designed an online learning environment about electron deflection in fields using specific tasks, online experiments, support elements and feedback to overcome these limitations. Our environment is available online at <http://www.virtual-experiments.com/> (German, English, and French versions). User tracking shows that the environment is frequently used by teachers and students in Germany.

For research purposes, we developed two different environments, one focusing on the connection between theory and experiment (the experimental-inductive method) and one focusing on the equations of motion (the mathematical-theoretical method). In a laboratory study with 80 students we observed success in hypothesis testing with the experiment as well as differences in knowledge acquisition in specific domains when using the mathematical or the experimental method. Results show a satisfying success rate in hypothesis testing. The mathematical method demonstrated greater knowledge acquisition about forces than the experimental method.

1 Introduction and Theory

Experiments have always been an important part of physics courses. In Germany, two-thirds of class time is determined by preparation, processing and interpretation of experiments (Tesch, 2005). Experiments serve diverse roles in the teaching and learning process. For example, experiments are used to visualize effects, to motivate students, to test hypotheses or to generate a mathematical description (Etkina, 2002; Koponen & Mäntylä, 2006). Moreover, teachers have different intentions when using experiments in their classes, especially regarding computer simulations and inquiry-based experiments (Zacharia, 2003). Welzel et al. (1998) distinguish five main categories for the use of experiments: connecting theory and experience, acquisition of experimental abilities, learning about scientific thinking, motivation of students, and testing of knowledge. These categories can also be used for experiments realized as computer simulations or as online learning environments.

When using a simulation or a computer-based experiment, however, some conditions of the experiment cannot be influenced by the teacher. The developer of the program designs important parts and affects the possible uses of the experiment. An example for such an experiment where the developer determines the main topic of investigation is the virtual lab of the University Bayreuth for [measuring the specific resistance](#). This laboratory focusses on experimental abilities and scientific thinking. Conversely, the simulations of the PhET-project, for example [Energy Skate Park](#), focus on the connection between theory and experience and on the motivation of students. Moreover, computer-based experiments can

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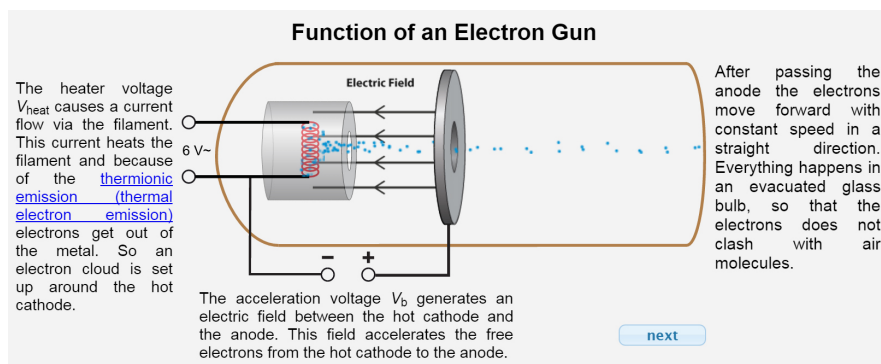


Fig. 1. Function of an electron gun described above (in the environment, electrons are animated).

provide support along the intended learning path in different forms (cf. Chapter 2).

Nevertheless, it is important to check in detail which skills students learn or train when conducting an experiment, regardless of whether it is a laboratory experiment or a simulation. Studies have shown that the intended learning goals are not always reached (Hofstein & Lunetta, 2004; Yeo, Loss, Zadnik, Harrison, & Treagust, 2004).

1.1 Advantages of Computer-Based Experiments

Connecting experiments with prior knowledge and relevant social and personal issues is important to help students learn (Murphy, Lunn, & Jones, 2007). This is primarily a task that should be managed by teachers. It can be made easier, however, when computer-based experiments contain relations to prior topics or use relevant examples. Moreover, a learning environment can provide individual feedback about the learning progress for every student and present a summary.

1.2 Components for Scaffolding

From the learners point of view, clear intuitive interface within a website or a simulation is critical. For this reason, it is important to provide solid structure and easily understood controls. Furthermore, the tasks should be clear so that cognitive resources can be focused on the learning process. On this point, an online environment is helpful if it provides an integrated working space with all necessary information. This way, students won't have to switch between online and offline activities frequently and won't get distracted by searching the web and exploring websites (Zhang & Quintana, 2012). Moreover, digital environments can guide and support students in the learning process. Worked-out examples and tips about the experimental approach can support scientific thought as well as productivity; it can also make learning more efficient (McLaren, van Gog, Ganoë, Karabinos, & Yaron, 2016). Content-related hints can be adapted automatically to the students' knowledge and individual feedback can be displayed in the middle of the students' learning process (Richtberg & Girwidz, 2015). Giving feedback is important in influencing learning (Hattie & Gan, 2011). Often feedback is most powerful when it is presented in the working and learning process (Van der Kleij, F. M., Feskens, R. C. W., & Eggen, T. J. H. M., 2015). For a single teacher it is impossible to provide such feedback to every student, which is why the support of computers is advantageous.

In addition to these support tools, a developer of a learning environment has some more subtle tools to influence and support the learning process. The developer defines the variables which can be varied by the user and sets all of the rest to fixed values. Also the developer can structure the learning process in sub-steps or pre-set tasks and tables. A teacher cannot change this default setup while working within the environment.

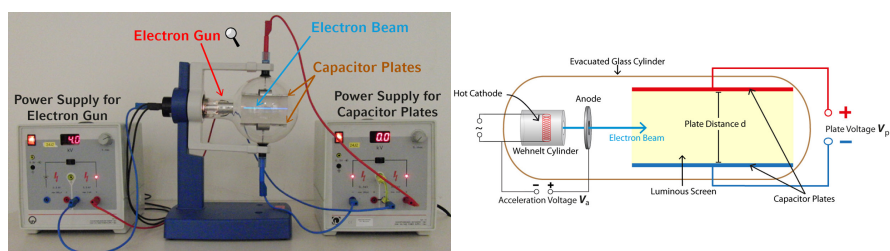


Fig. 2. Experimental setup with a picture of the experiment and a schematic diagram.

1.3 Visualization

A powerful feature of multimedia is the possibility of visualizing effects in different and descriptive ways. This is especially beneficial when important parts of an experiment are barely recognizable or even invisible. For example, electric and magnetic fields are invisible and often hardly measurable. By contrast, in a computer-based environment such fields can be displayed easily and made understandable. Moreover, it is possible to display more than one illustration at the same time. Different forms and types of visualizations can be presented simultaneously -in parallel or even merged together. Thus, information from many representations are available in the learning process. Moreover, such multiple representations can foster cognitive flexibility (Ainsworth, 1999). Finally, computer visualizations are not limited to static pictures; they can also serve as part of animations and can react and adapt to user input. A challenge is to keep cognitive load in check when using multiple representations (Sweller, 2009).

2 Implementation of Different Learning Goals

The acceleration of electrons in an electric field and the deflection of electrons in electric and magnetic fields represent important parts of the current secondary school curriculum in Germany. Moreover, the mathematical theory and the experimental observations in this topic are heavily connected. Unfortunately, it is difficult to perform experiments in this area because they require expensive equipment. Furthermore, most experiments require high voltage sources and so usually are too dangerous for students to perform independently. For this reason, we decided to develop a learning environment to increase the number of student activities in this topic. Students can perform experiments on their computers and can analyze the results on their own. In regular classes different approaches to this topic are possible. Given this, we developed two generic learning courses. The intended learning goals of both modules differ distinctly. The following provides a description of the first steps of the students in learning electron motion and electron deflection in electric fields using the digital learning environment. These steps are equivalent for both learning paths and both relate to the prior knowledge of the students. Afterwards, differences between the two courses are described.

2.1 Connecting to Prior Knowledge

The force on an electron in the electric field of a plate capacitor is discussed in 9th grade and repeated in 11th grade. The connection to this prior knowledge was realized by the video of an experiment with a charged graphite ball in a plate capacitor. After that, every student worked separately on a laptop with the learning environment. At first the experimental setup of an electron gun was shown and its function was described (fig. 1). In the environment, the electrons were animated according to physical laws.

After that, the acceleration of the electrons is described mathematically and the equation for the velocity of the electrons when passing the anode is deduced. Thereafter, a simulation allowing students to change heating and acceleration voltage depicts all of this.

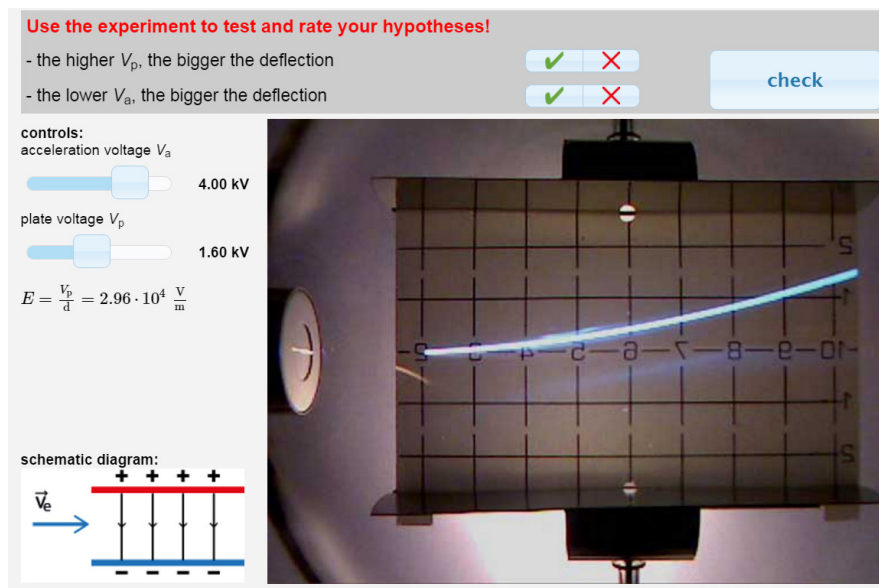


Fig. 3. Testing and rating the chosen hypotheses with the virtual experiment.

Finally, the experimental setup of an electron deflection tube is presented with a picture of the real setup and a schematic diagram (fig. 2)

Based on this knowledge, students have to choose between hypotheses about the influence of the acceleration voltage and the plate voltage on the path of the electrons. An animation introduces the virtual experiment and presents the controls. With this experiment, students have to check and rate their chosen hypotheses (fig. 3).

Overall, this intro will support a qualitative understanding of the experimental setup and the influence of the two adjustable variables on the electron trajectory.

3 The Mathematical-Theoretical Way

The focus of the mathematical-theoretical formulation is on the forces acting on the electrons. At the outset, students determine which forces act on the electron in the x- and y-directions (horizontal, and vertical respectively) while moving through the electric field of the deflection plates. Consequently, there is constant motion in the x-direction and uniformly accelerated motion in the y-direction. The corresponding equations of motion are displayed and students have to generate the $y(x)$ -function for the electron trajectory. In this process, learners have to use the substitution method multiple times. For these tasks, the environment provides an augmented reality feedback. Students enter their solution in the environment and the computer plots the function directly overlaid with a picture of the real experimental output (fig. 4). Here, the plot provides elaborated feedback and offers much more information than just proclaiming whether the function was right or wrong.

Here the experiment is used to verify a mathematical theory. Using this method, students should know the forces acting on the electron as well as the substitution method.

3.1 The Experimental-Inductive Way

The second learning path focusses on the experiment itself. Here, tasks like collecting and analyzing data are important. Based on knowledge of proportionality, a mathematical description of the electron trajectory should be derived. In a first step, students are tasked

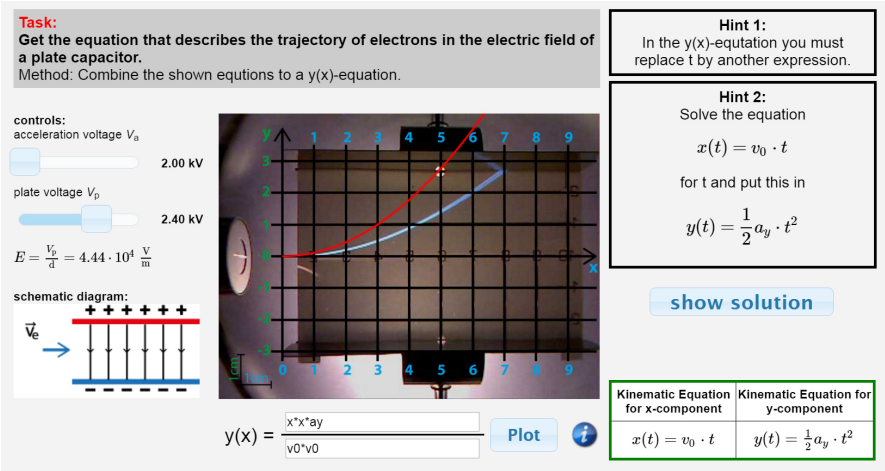


Fig. 4. Generating a function using the kinematic equations and substitution with hints displayed.

with quantifying the qualitative results about the influence of acceleration voltage and plate voltage on the electron trajectory. From this, the proportionality between plate voltage and deflection $y(x)$ must be verified. Here, a table structures the experimental process and manages the calculations (fig. 5).

Likewise, the inverse proportionality between acceleration voltage and deflection $y(x)$ must be shown likewise. Based on these insights, learners have to create a mathematical description of the electron trajectory. Formula modules support this step and the plot of the chosen function over the picture of the experiment again work as elaborated feedback.

Using the experimental-inductive method, students should know how to verify proportionality and inverse proportionality; they should also be able to infer the implication of varying a parameter on the electron trajectory.

4 Design of a Laboratory Study

To investigate the effects of the two different learning paths and to check whether our intended learning goals were reached, we conducted a laboratory study. Participants consisted of eighty students from four different schools in Munich and Rosenheim. One half of the students were assigned the mathematical-theoretical module while the other half took the experimental-inductive module. Group membership was assigned at random. Both groups started with the presentation of the charged graphite ball in a plate capacitor described above. After this, each student was provided with a laptop with access to the learning environment. At the beginning, eight selected items from the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) concerning the principle of superposition had to be answered in ten minutes. Then, in five minutes, four questions about the properties of the uniform electric field in a plate capacitor had to be answered. Thereafter, in twenty-five minutes, the students could work with their version of the learning environment. Hypotheses had to be chosen, tested, and rated and the mathematical description of the electron trajectory had to be derived. All interactions between learner and environment were logged into a database. Thus, the individual learning paths were documented.

The post-module test took twenty-five minutes and used paper and pencil test. Students had to predict the effect of varying acceleration or deflection voltage in linguistic and graphical way. Also, proportionality and inverse proportionality had to be verified and the mathematical description of the electron trajectory had to be deduced using the substitution method. For data analysis, IBM SPSS 22 was used.

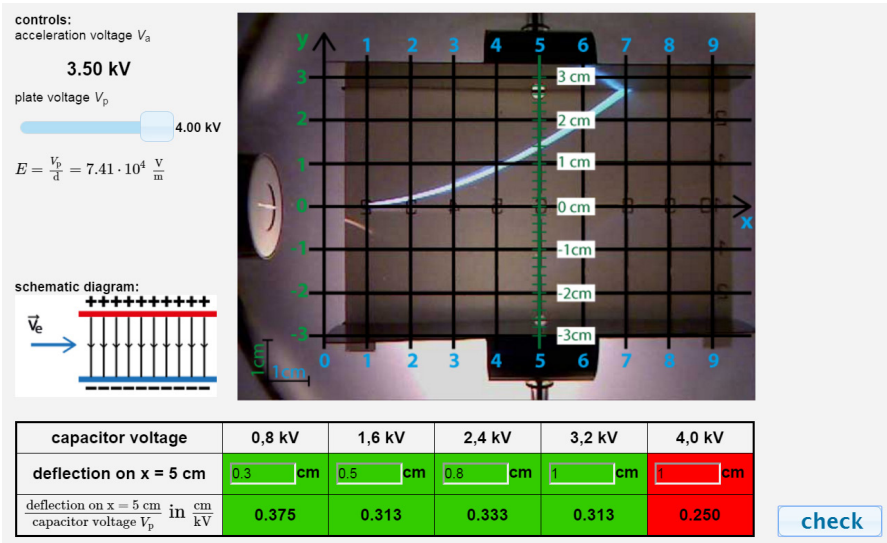


Fig. 5. Verifying the proportionality between capacitor voltage and deflection.

5 Results

As expected, the pre-test showed no significant differences between users of the mathematical-theoretical and the experimental-inductive way. Thus, the two groups had a similar level of knowledge concerning superposition and the configuration of the electric field in a plate capacitor. Furthermore, there were no significant differences in the success rate when testing hypotheses with the virtual experiment. The success rate in testing the hypothesis about the influence of the deflection voltage was ninety-five percent. compared to eighty percent for the hypothesis on the influence of the acceleration voltage.

Both groups used the experiment in a similar way. There were no significant differences between the groups in the quantity of the experimental activities (changing a parameter). However, we found great varieties between individuals. For example, between one and one hundred and nine parameter changes were counted before students finished checking and rating the hypotheses (Mdn = 22, SD = 17.7).

The post-test showed that students who applied the mathematical-theoretical method significantly outperformed those students using the experimental-inductive method in questions about the forces acting on the electrons. As expected, these students also achieved significantly better results in tasks about the derivation of the mathematical formula about the electron trajectory. Contrary to our expectations, students using the mathematical-theoretical way did not achieve higher scores in items where proportionality should be verified. Also, no significant differences were measured for questions which dealt with effects on the electron trajectory caused by variation of experimental parameters.

6 Discussion

Results show that students use the option to vary the experimental settings. The total number of experimental activities varies strongly between individuals, however the median of 22 (SD = 17.7) is adequate for the complexity of the experiment and the degrees of freedom. The success rate in hypothesis testing is very good, especially for the hypothesis about the influence of the voltage applied to the capacitor. The reason for the slightly lower success rate for the influence of the acceleration voltage should be explored in more detail in subsequent studies. One reason might be that the influence of the velocity in x-direction

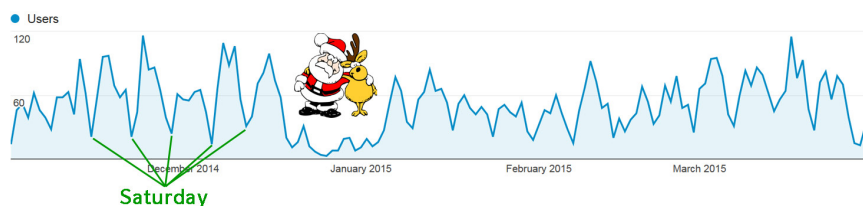


Fig. 6. Distinct users per day between November 1st 2014 and March 31st 2015.

on the deflection in the y-direction is not that easy to understand for students.

The fact that students who worked in the mathematical-theoretical module outperform the other group in questions about forces and the substitution method is consistent with our hypotheses. These were central objectives of this learning module and were achieved by the majority of the students. That no significant differences were found in tasks about the influence of experimental parameters on the electron trajectory or the verification of proportionality requires further research.

7 General Usage and Perspective

The learning environment is not only used for our laboratory study, but is also available online for a broader user community. Teachers and students are free to use it. Besides the deflection of electrons in an electric field, there are more free applets available. For example, there are experiments available addressing electron deflection in a magnetic field, specific charge measurement of an electron, and the introduction to electron optics. Furthermore, it is possible to track every user interaction with our website. A general question is whether teachers use computer-based environments in their classes and which pages are the most interesting for students. For this, Google-Analytics and Piwik are suitable tools. Moreover, these tools provide data on which devices and operating systems are used.

Based on filtered Google-Analytics data (without bots, referrer spam, and invalid hostnames) over a period of five month between November 1st 2014 and March 31st 2015, more than nine thousand visits from more than six thousand users were counted. The diagram below clearly indicates that on Saturdays and holidays the traffic is much lower (fig. 6) (Obviously students enjoy their weekends.) The average visit duration was over nine minutes. Surprisingly, the most visited pages were not the ones with tasks or worked out examples, but rather the pages with experimental settings, derivation of formulas and the simulation of the electron gun. Our data also show that teachers used the websites in their classes. Ten to fifteen users with a single IP at the same time indicates that here students mostly worked with partners.

It can be concluded that online environments are a powerful, efficient tool to foster learning and can reach many students.

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A Solar Panel Virtual Laboratory

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Currently, virtual and remote laboratories plays an important role in the learning process. For distance education in scientific areas, where laboratories are an essential part of the curriculum, this importance is especially pronounced. This study presents an online virtual laboratory of solar cells. The virtual lab allows students to study the behavior of this system by changing its parameters. Using this method, the users obtain estimates of the system output for a wide range of states, and become better prepared for the remote version of the laboratory with real equipment.

1 Introduction

Nowadays, traditional face-to-face education can be complemented with online applications, the latter of which have an important role in the learning process of the students. Fortunately, there are many free Internet resources that can help with various aspects of education already. In this area, engineering and scientific studies need specific Internet-based tools to complement the practical, hands-on, part of their lessons. Considering the need for this experimental knowledge and the distance education paradigm, the use of on-line laboratories is an essential part of education and research. For this reason, web-based virtual labs should provide computer based simulations that offer an experience similar to the traditional counterpart to the user. These kinds of laboratories have evolved over the last decade into interactive graphical user interfaces that support some level of user interaction and control over the system.

The use of photovoltaic systems (PV) have become widespread thanks to new technologies and concern for the environment. This has caused an increase in the number of students who choose to specialize in this area, in order to gain experience in design and usage of PV systems. The link between theoretical and practical knowledge, however, should be developed by experimentation.

This work presents a virtual lab on the configuration and performance of solar cells. This laboratory contains different components to develop at least eight different exercises in the laboratory. Additionally, the remote version of this laboratory is now in development and complements the results of the virtual one.

This paper is organized as follows. Section II describes the current state of the virtual solar panel lab. Section III present some of the laboratory practices that can be carried out by the users, including changing the different parameters in the simulation. Finally, section IV gives some final conclusions.

2 The Solar Laboratory

The virtual lab is created using the open source tool Easy Java/Javascript Simulations (EjsS). EjsS is designed to create many kinds of simulations by teachers or students who want to make functional applications. This tool offers an easy way to simulate dynamic

Sáenz, J., de la Torre, L., & Dormido, S. (2016). A Solar Panel Virtual Laboratory. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 43–49). Mulhouse: European Physical Society.

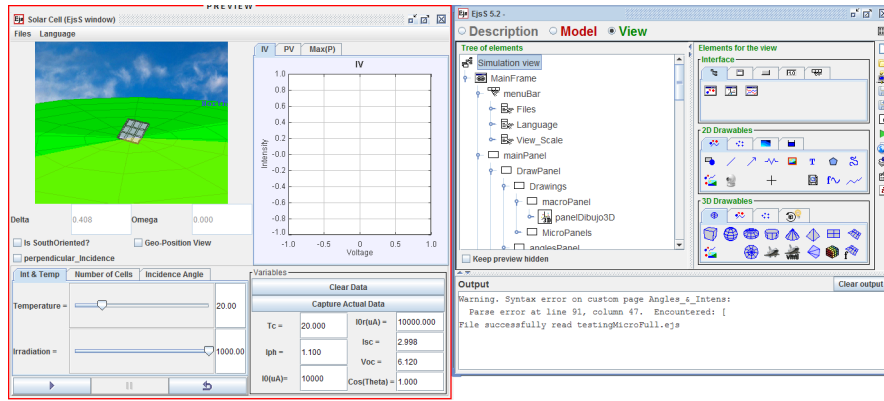


Fig. 1. Main view of the EjsS editor. The View tab contains the GUI editor defined by a tree structure of graphical elements from the right panel.

systems by introducing either the differential equations of the system or the programming code needed to define the system behavior. EjsS also provides a graphical user interface (GUI) editor to build the main view of the application by dragging and dropping elements into a tree structure. Fig 1. shows an example of the EjsS editor. The developers can design this GUI to capture user interactions with the model by using elements like fields, sliders, buttons and plots.

In this regard, this tool facilitates the development of laboratories and applications without requiring the technical programming aspects (Farias et al., 2010; Chacon et al., 2015).

The solar panel laboratory developed in this work provides the user with a collection of sliders and fields to modify parameters and obtain the characteristic curves. Some of the fields that the student can change include:

- Environmental variables such as irradiance and temperature.
- Configuration parameters, such as the number of serial and parallel cells in the array.
- Geographic and time-related parameters like latitude, longitude, date and local hour
- Orientation angles for the simulated solar panel.

2.1 Characteristic Curves

As the solar panel lab is intended to be a preliminary laboratory to enhance the theoretical background of the student, the system must provide useful information about the actual state of the system. In order to analyze the behavior of the PV system, this virtual system is developed using intensity-voltage and power-voltage plots, which make up the characteristic curves of a PV System.

The characteristic curve of a solar panel is well-known and describes the PV cell model as a circuit. This circuit has been studied in many examples cited below: Ozkop et al (2014), Eteiba et al (2013). The relation used to simulate the cell behavior is given in Eq.1 and. It contains advanced and basic terms of the model because this lab has been developed to be used by students with different skills,

$$I = I_{ph} \cdot \cos \theta - I_0 \cdot \left[e^{\left(\frac{q(V_c + I \cdot R_s)}{m k T_c} \right)} - 1 \right] - \frac{(V_c + I \cdot R_s)}{R_{sh}} \quad (\text{Eq.1})$$

In Eq. 1, m is a fitting constant for the I - V characteristic, k is the Boltzmann constant, e is the electron charge, I_{ph} is the photocurrent, I_0 is the reverse saturation current of a diode, R_{sh} is the parallel resistance, T_c is the operating temperature of the cell, V_c is the output voltage, R_s is series resistance, I is the output current and θ is the incidence angle. The next subsec-

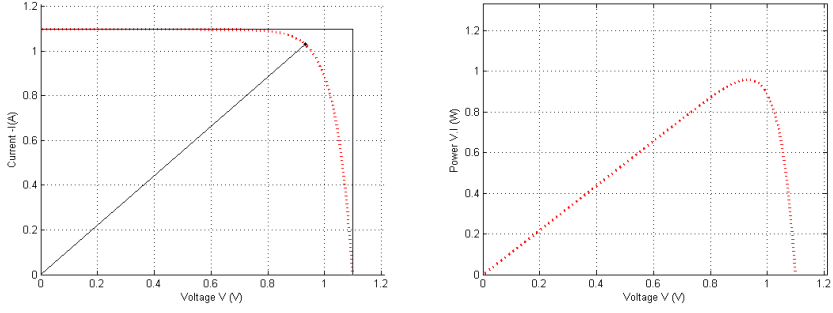


Fig. 2. Left. Characteristic I - V curve of a solar cell, contains information about the cell behavior, like the short circuit current, open circuit voltage and maximum power point (Mpp). Right. Characteristic P - V curve of a solar cell.

tion contains the equations that link the main parameters with the environmental, position and orientation changes. Fig. 2 shows typical curves obtained by solving this equation and some information that can be obtained from the plot.

2.1.1 Effects on Characteristic Parameters

As stated in the previous section, the user can interact with the GUI by changing the parameters of the solar panel. After each change, the simulation solves Eq. 1, obtaining the V_c - I pairs of the fourth quadrant. The application then updates the intensity-voltage and power-voltage plots. Below the interface, the simulations must include the links between variables and main parameters in their calculations. The next sections present how these changes are included in the simulation, where some of the values used are obtained from the datasheet of a real solar panel from our laboratory.

Cell Operating Temperature: T_c

Students are able to select the ambient temperature and irradiance as environmental parameters, but these changes directly affect the operating temperature T_c among other variables. Eq.2 has been included in the simulation to consider this dependency between the variables. In this instance, $NOCT$ is taken from the solar panel datasheet, calculated for a wind speed of $w = 1\text{m/s}$, ambient temperature of $T_a = 20^\circ\text{C}$, and hemispherical irradiance $G = 800\text{ W/m}^2$.

$$T_c = \left[\frac{NOCT - 20}{800} \right] \cdot G + T_a \quad (\text{Eq.2.})$$

Photocurrent and Reverse Saturation Current: I_{ph} and I_o

As seen in Eq.2, any change in the irradiance or ambient temperature affects the operating temperature, and in the same way, these changes affect the current generated by the photoelectric effect Eq.3 and the reverse saturation current Eq.4 of the diode model.

$$I_{ph} = [I_{phr} + K_i \cdot (T_c - T_r)] \cdot \left(\frac{G}{G_r} \right) \quad (\text{Eq.3.})$$

$$I_o = \left[I_o \cdot \left(\frac{T_c}{T_r} \right)^3 \right] e^{\left[\frac{qE_g}{kT_m} \left(\frac{1}{T_r} - \frac{1}{T_c} \right) \right]} \quad (\text{Eq.4.})$$

$$I = \left[\frac{I_{scr}}{e^{\left(\frac{qV_{oc}}{mN_s k T_c} \right)}} \right]$$

Where I_{phr} is the photocurrent at reference conditions, K_i is the temperature coefficient of the short circuit current, T_r is the reference cell operating temperature (25°C), G_r is the reference irradiance (1000 W/m²) and V_{ocr} is the open circuit reference voltage. These equations show complex dependence between a wide range of parameters, like environmental conditions, temperature or irradiance, or microscopic parameters, such as the band-gap energy of the semiconductor, E_g .

Open Circuit Voltage and Short Circuit Current: I_{sc} and V_{oc}

I_{sc} and V_{oc} are two values that can be obtained using these equations for any change in the initial condition. Equations Eq. 5. and Eq. 6. are then included in the simulation but do not affect the characteristic equation.

$$I_{\text{sc}} = [I_{\text{scr}} + K_i \cdot (T_c - T_r)] \cdot \left(\frac{G}{G_r}\right) \quad (\text{Eq.5})$$

$$V_{\text{oc}} = [V_{\text{ocr}} + K_v \cdot (T_c - T_r)] \quad (\text{Eq.6})$$

Inclination and Orientation Parameters: β , θ , δ , ω and φ

As an important part of the solar panel configuration, the users must consider how to obtain an incidence angle of the sunlight close to 90°, perpendicular to the panel surface. In most cases, the configuration requires a compromise between the inclination and orientation to obtain the required characteristics.

The simulation considers geographic, time-related parameters and orientation angles to obtain the final incidence angle of the incident light. This has been studied and discussed by many studies (e.g. Rebé et al (2013)), yielding Eq.7.

$$\begin{aligned} \cos \theta_i &= \sin \delta \sin \varphi \cos \beta - \cos \varphi \sin \beta \cos \gamma \\ &+ \cos \delta \cos \omega \cos \varphi \cos \beta + \sin \varphi \sin \beta \cos \gamma \\ &+ \cos \delta \sin \beta \sin \gamma \sin \omega \end{aligned} \quad (\text{Eq.7})$$

Here, β is the inclination angle between the panel and the horizontal plane, γ is the azimuthal angle, δ is the declination angle which depends on the date, ω is the solar angle related to the local hour and θ_i is the angle of incidence.

2.2 The User Application

The Fig.3 shows the basic structure of the virtual laboratory (VL) where the simulation window is divided into three sections: a menu, the system 2D graphical representation and control, and the evolution graphs and indicators.

- Menu: In the top left corner of the VL's user interface, there are two buttons to select the language or to save data and figures.
- System representation: A 2D representation of the system, a solar panel with the inclination and orientation selected. Under this visualization zone the application shows three tabs:
 - Temperature and irradiance tab, which contains 2 sliders and numerical fields to select both environmental parameters.
 - Number of cells tab, where the user can select the number of serial and parallel panels in the array.
 - Incidence angle tab contains six sliders to select the geographical position, latitude and longitude, date, local hour and inclination parameters, inclination and orientation.
- Evolution graphs and variable indicators in the right part of the GUI, where the simulations plot the characteristic curves and update the values of main parameters.

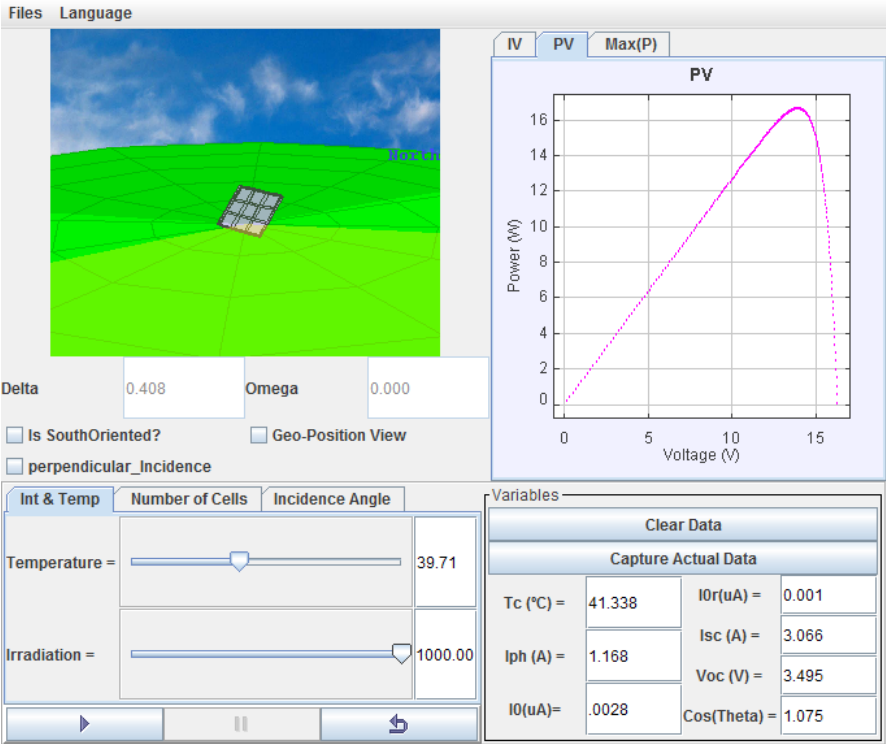


Fig. 3. Three sections, menu, system representation and evolution graphs of the main view of the user application.

3 Virtual Laboratory Practices

The next sections shows some of the classic practices that can be completed by the students. The teacher could combine it or build others to enhance the learning process. All of these practices can be completed using just the visual representation. Advanced users can also obtain numerical data and use a mathematical program such as Matlab.

3.1 Temperature and Irradiance

In this kind of practice, the objective of the simulations is to teach how solar irradiation and temperature affect output current and voltage, and thereby also the power produced by the solar panel array. The equations included in the solar panel model, described in the previous sections, allow students to configure the array and analyze the effects quantitatively or qualitatively. The Fig. 4 represents usual graphs of characteristic curves for different temperatures and irradiances. The curves for increasing temperature show how the open circuit voltage decreases while the short circuit current maintains an almost constant value. When the user plots the curves for different irradiances, the graph shows how the short circuit current decreases with the irradiation maintaining a constant value for the open circuit voltage.

3.2 Geographic, Time-Related, Orientation and Position

With practice, changing these geographical, time and date parameters allows for in-depth analysis. For example Fig. 5 shows the changes in the maximum power obtained from the panel along a year, or in the same day, and how the characteristic curves are modified when the user chooses different latitudes or solar panel inclinations.

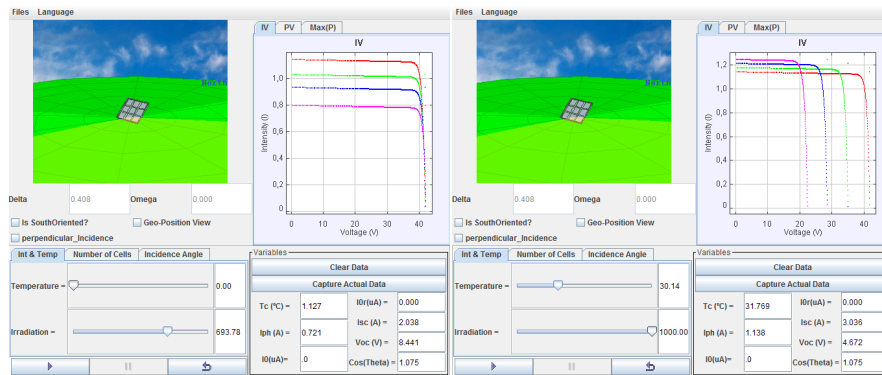


Fig. 4. Left. Curves for a decreasing irradiance. Right. Curves for a increasing ambient temperature.

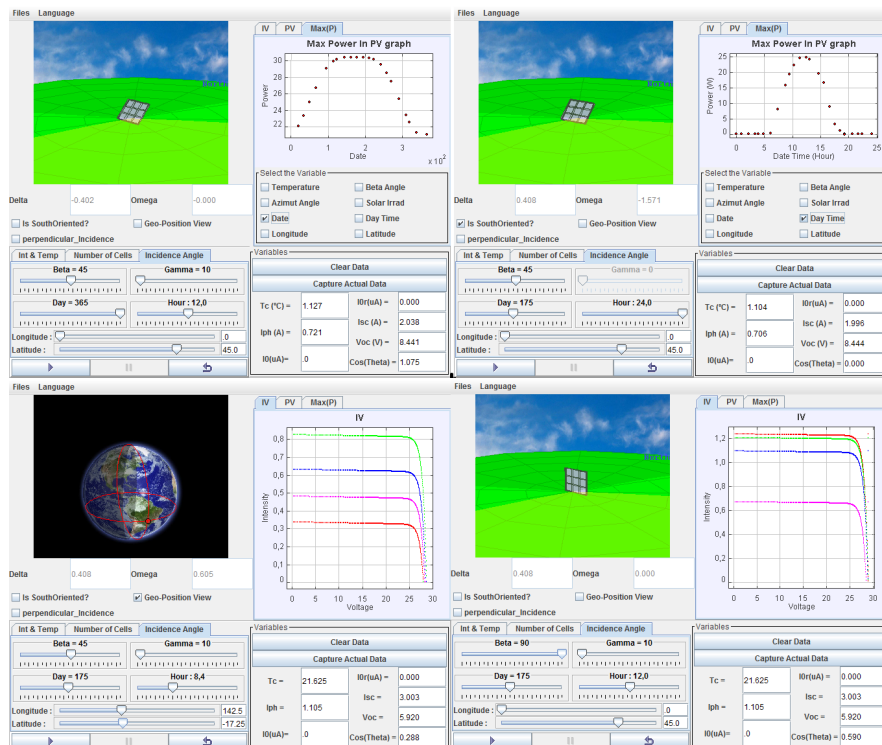


Fig. 5. Upper-Left. Maximum power for the different days in a year at 12h. Upper- Right. Maximum power obtained from the solar panel during the day. Bottom-Left. Changing latitude to obtain the characteristic curves. Bottom-Right. Changing inclination to obtain the characteristic curves.

3.3 Solar Cell Characterization

In engineering and sciences studies, the mathematical characterization of the solar cell is a common exercise. To achieve this objective, the student can use a circuital model as complex they need. From this, a student can obtain the basic parameters of the solar cell by mathematically analyzing the characteristic curve representing voltage and intensity in a semi-logarithmic plot, such as the one shown in Fig. 6.

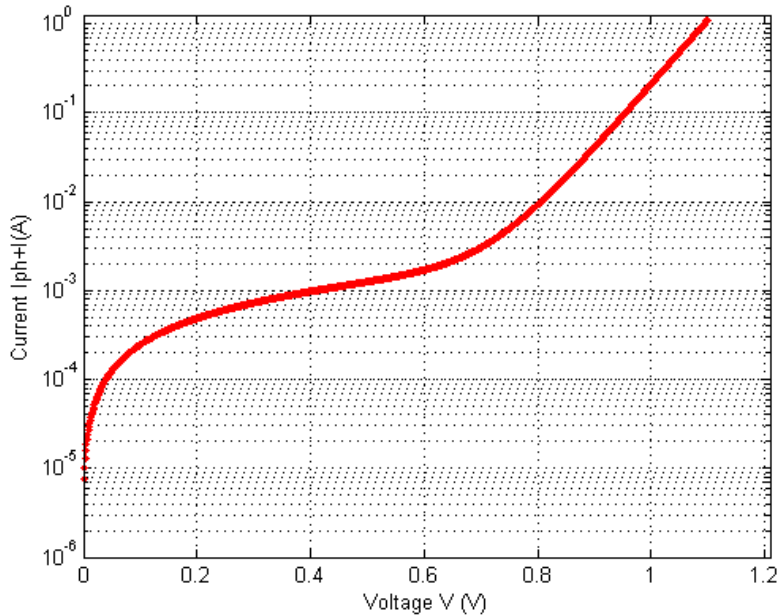


Fig. 6. Voltage and intensity in a semi-logarithmic plot.

4 Conclusions

The results of this laboratory show that computer based simulations offer students a collection of exercises and laboratory practices without requiring the associated physical devices. Until the completion of the remote version, however we have no information about the impact on student learning. This lab offers a way to work offers some additional advantages, such as the adjustable parameters and the potential to serve as a stepping stone to a remote laboratory. Additionally, the numerical and graphical data obtained during the simulation can be stored easily in .m files for later analysis with mathematical software such as Matlab. This functionality enhances the possible practices that can be done with this laboratory.

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SUPPORTING LAB WORK WITH MULTIMEDIA

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Use of QR-Codes to Provide Information and Assist Learning in Lab Courses

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In the *physics for higher education* program at the LMU Munich, students attend seminars on the topic of experimentation in schools where they set up experiments on their own. Students do not always operate the equipment correctly. In the worst cases, damage caused by faulty operation can occur. To help students to access data sheets and manuals and to encourage them to conduct thorough inspections, we have digitalized data sheets and manuals for these labs and have attached QR codes to the lab equipment. By scanning these codes with a smartphone or a tablet, students receive device-specific information over the Internet. Initial results show that students are receptive to the additional information medium.

1 Introduction

In addition to their regular physics lab course, students of physics for higher education at the Ludwig-Maximilians-Universität München attend two seminars on the topic of experimentation in schools where they set up experiments on their own. Despite the fact that data sheets and manuals for the lab equipment are available and students are explicitly asked to read the material before setting up an experiment, they do not always operate the equipment appropriately. In the worst cases, damage caused by faulty operation can occur.

In an exploratory interview study, students cited lack of knowledge on appropriate operation of lab equipment as the main reason for a failure in experimentation. Due to a lack of time during preparation, students did not adequately read the data sheets and manuals.

1.1 Empirical Background

Research on physics lab courses has shown that difficulties students encounter while experimenting may be partly attributed to the complexity of the experiment as a learning environment (Nakhleh and Krajcik, 1994). This complexity is compounded by the often solitary use of equipment that is new and strange to students (Aufschnaiter, 1999). Whenever learners encounter unfamiliar devices, experimental activities are initially based around exploring the use of these devices (Aufschnaiter, Aufschnaiter, & Schoster, 2000). Moreover, the content of discussions between students during lab work is largely determined by the experimental set-up; when students encounter unfamiliar equipment, they tend to focus on these experimental tools (Haller, 1999; Huckle, 1999; Theyßen, 2000; Sander, 2000). As a result, this cognitive load allows little room for discussion on either the task that they have to perform, or the underlying physics concepts.

1.2 QR Codes Assist Experimentation and Provide Several Kinds of Information

Every device has received a unique QR code to facilitate clear identification. If this code is scanned with a smartphone or tablet it leads to a web site showing several pieces of information. At first, a photograph is shown. This gives the user direct feedback to confirm that the information displayed corresponds to the scanned device. After this, a list follows

Thoms, L.-J., Nagel, A. L., & Girwidz, R. (2016). Use of QR-Codes to Provide Information and Assist Learning in Lab Courses. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 53–58). Mulhouse: European Physical Society.

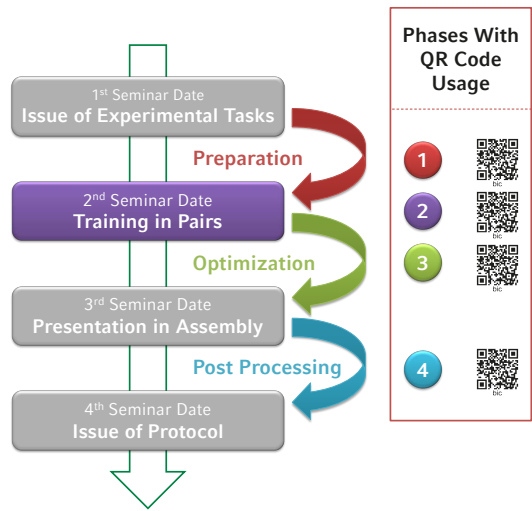


Fig. 1. Learning sequence in the seminar and stages with the possible use of QR codes. Students process an experimental task over three weeks. First, the task is issued, then there is one week of preparation time followed by training on experimental methods and presentations in person. Next, there is one week for optimization, followed by presentation in front of the assembly, and then one week of post processing, and, finally, the issue of a report.

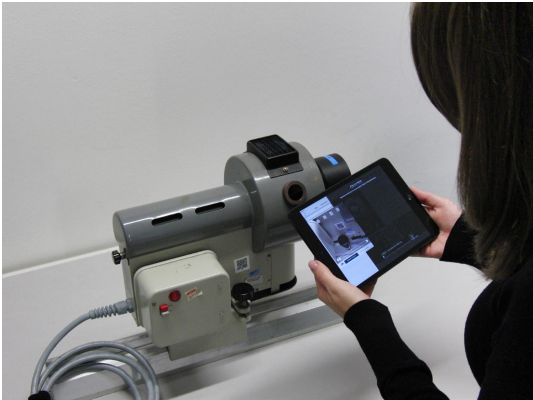


Fig. 2. Students can scan QR Codes from a task sheet or directly from a device.



Fig. 3. Example of a device's QR Code.

with linked documents, e. g., data sheets, manuals, and descriptions of experiments. Furthermore, video tutorials may be provided showing, e. g., exemplary experimental set-ups, experiment instructions, or security advice. A section links connects to external sources such as manufacturers' web sites, further experiment instructions, or videos of experiments conducted. Furthermore, the device may be linked to the web-based collaboration platform used at the institute as a learning platform. Finally, inventory information such as the device's manufacturer, inventory number, and storage location is displayed. This helps students return the device back into the collection appropriately after use.

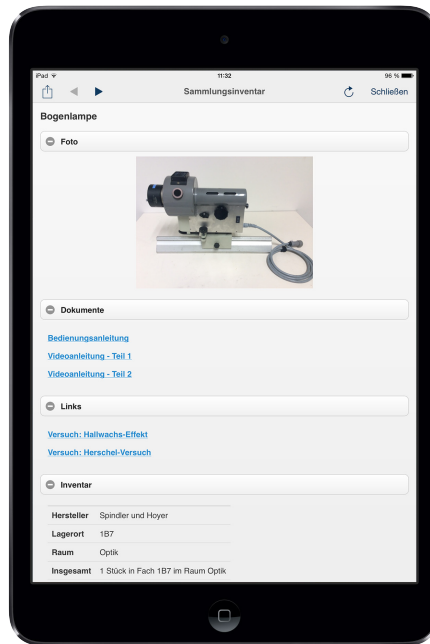


Fig. 4. After scanning the QR code a device specific web page will be displayed on the tablet, smartphone or PC.

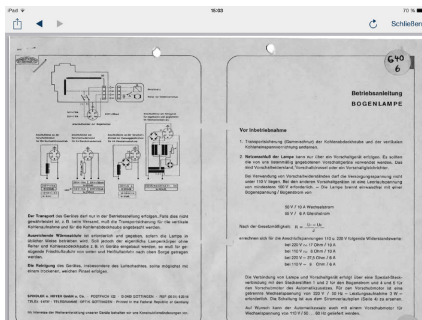


Fig. 5. Linked data sheet.

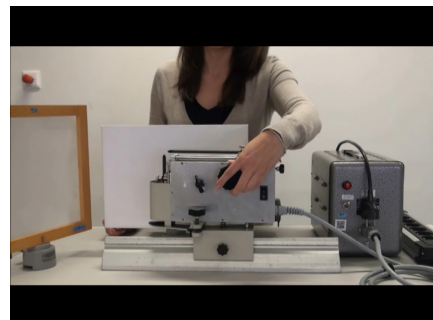


Fig. 6. Linked video tutorial.

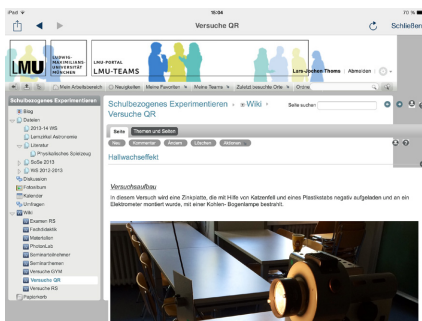


Fig. 7. Linked experiment instructions.



Fig. 8. Inventory information and details regarding the storage place facilitate organization.

Group	Preparation 1	Training 2	Optimization 3	Post Processing 4	Topic of the Experimental Task
1	++	+			Herschel Experiment
2	++	++	++	+	Radiation Shielding
3	+				Color Spectra/Color Mixing
4		++	++	+	Inverse-Square Law
5		+	+		Human Eye
6		+			Cloud Chamber*

Tab. 1. Processing depth of different QR codes in the summer term 2014 by group of students and learning phase. () no QR code accessed; (+) at least one QR code accessed; (++) at least one QR code and respective link accessed. *The cloud chamber was given out with a printed manual.

2 Experiences and First Results

In the following, we describe representative experiences and initial results from three seminars on experimentation in schools. The courses in the winter term were comparable, except that the duration of the preparation phase was changed from one week to two weeks.

2.2.1 Summer Term 2014

To examine how students received this new mode of information, we analyzed the user behavior in the summer term of 2014. We gave out six experimental tasks (e.g., the Herschel-Experiment) to students with printed QR codes referencing the equipment (e.g., an arc lamp, or a Geiger-Müller tube) needed to conduct each experiment. We paid special attention to the stage within the experimental process at which students used the QR codes to gain information or develop experimental skills (see fig. 1).

Of the 18 QR codes printed on the task sheets, 17 were used. The code that was not used was the fifth code on the distinct task sheet. Hence, each group used up to four QR codes. If the devices proposed on the task sheets were not available, students did also look for alternative devices and then scan the QR codes on those devices to gain information.

2.2.2 Winter Term 2014/15

In the seminar on experimentation in schools in winter term 2014/15, we gave out eight experimental task sheets with three to seven QR codes on each task sheet linking to devices required for each experiment (e. g., Magdeburg hemispheres, radiometer etc.). The last QR code of every task sheet linked to literature stored on our learning platform.

Particular attention was paid to the stage in the experimental process at which different QR codes were used by each group. It was noted that in the preparation time five out of six student groups scanned the QR codes and only one group followed the links shown on the web sites. In the training phase all groups scanned QR codes but only two groups followed the links. No QR codes were scanned in the optimization or post-processing phases.

Group	Preparation 1	Training 2	Optimization 3	Post Processing 4	Topic of the Experimental Task
1		+			Gay-Lussac and Entropy
2	++	+			Thermal Expansion
3	+	+			Anomaly of Water
4	+	++			Hot-Air Engine
5		+			Convection
6		++			Thermal Radiation
7	+	+			Phase Transitions
8	+	+			Pressure

Tab. 2. Processing depth of different QR codes in the winter term 2014/15 by group of students and learning phase. () no QR code accessed; (+) at least one QR code accessed; (++) at least one QR code and respective link accessed.

Group	Preparation (two weeks) 1	Training 2	Optimization 3	Post Processing 4	Topic of the Experimental Task
1	++				Gay-Lussac and Entropy
2	++	+			Thermal Expansion
3	+				Anomaly of Water
4	++	++			Convection
5	++	++			Thermal Radiation
6	++				Pressure

Tab. 3. Processing depth of different QR codes in the winter term 2015/16 by group of students and learning phase. () no QR code accessed; (+) at least one QR code accessed; (++) at least one QR code and respective link accessed. The preparation phase has been extended to two weeks.

2.2.3 Winter Term 2015/16

In the seminar on experimentation in schools in winter term 2015/16, we gave out six experimental task sheets out of the eight task sheets from the winter term 2014/15. Unlike the former approaches, we extended the preparation phase up to two weeks.

Regarding the stage at which different QR codes were used and the depth to which they were processed in each group of students, it has been shown that during the preparation stage, every QR code was scanned at least two times and at most 25 times. The literature links were used particularly extensively. Again, the codes were not used during the optimization or post-processing phases.

3 Discussion

Regarding instructions for the experiments, the students generally integrated the additional information from the QR codes into their experimental process. However, the question arises as to how to determine a sensible maximum number of QR codes that students would be willing to scan.

It is clear that while the QR codes were used in the optimization and post-processing stages of the experiments in the summer term of 2014, they were not being used in the optimization and post-processing stages in the winter term seminars. It may be speculated that this might be due to the following: all students have to write reports on their experiments. The students in the summer term are rated on the basis of their reports. In the winter term, however, the students are not rated on the basis of their reports. Rather, students are required to write an exam at the end of the winter term. Thus, one might imagine that they do not put as much effort into the preparation of their reports.

However, it has been established that we should give the students two weeks rather than one week of time to plan ahead and prepare their experiments, as most of the students used that time to follow the links stored behind the QR codes.

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Collection of Solved Problems and Collection of Experiments in Physics: Worthwhile Connection of Two Online Learning Sources

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Nine years ago, we began to develop the Collection of fully Solved Problems. The Collection is designed to encourage students to take an active approach to problem-solving—that is, to solve at least some parts of a problem independently. Four years ago, the development of a “sibling” collection—the Collection of Experiments in Physics—began. Currently, the database contains about 1100 fully solved problems in Czech—750 in physics and 350 in mathematics. The database also contains more than one hundred problems in Polish and more than 120 problems in English. In addition to this, there are about 70 experiments described in great detail in the Collection of Experiments. The new approach is adding links between problems and corresponding experiments to enable teachers to use them together.

1 Introduction

Solving quantitative problems is a key ability which students should develop during their physics education. However, there is often insufficient time to solve enough problems during lessons to adequately develop this skill. Moreover, the amount of suitable materials for home study is very limited. This is particularly true for motivated students with poorer preparatory education (e.g. with less mathematical training) or for students of distance study programs. There are many collections of unsolved problems and several with solved problems, but solutions are usually very dense and do not stimulate active thought about the problem. For these reasons, we started developing the Collection of Solved Problems in Physics (Broklová Z. et al. 2007) nine years ago. We have developed a specialized structure of task solutions to encourage students in active problem solving—that is, solving at least part of a problem independently.

Three years after the Collection’s creation, the first solved problems in mathematics were added. Currently, the Czech portion of the Collection of Solved Problems is divided into two branches—physics and mathematics. At the same time, we began translating selected problems into English and since 2010 our colleagues from the University of Torun have prepared the Polish versions of some problems.

Both the database and the web interface turned out to be appropriate platforms for presenting materials in a “step-by-step” mode. As such, the idea to develop its “sibling”—a Collection of Experiments in Physics—emerged four years ago. We decided to use the same interface. The electronic medium for publishing experiments’ descriptions gives the writers a unique opportunity to enrich instructions with photographs and short video sequences. The Collection of Experiments is aimed primarily at physics teachers, so many technical and pedagogical notes are parts of experiments’ descriptions.

Koupilová, Z., & Kácovský, P. (2016). Collection of Solved Problems and Collection of Experiments in Physics: Worthwhile Connection of Two Online Learning Sources. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 59–64). Mulhouse: European Physical Society.

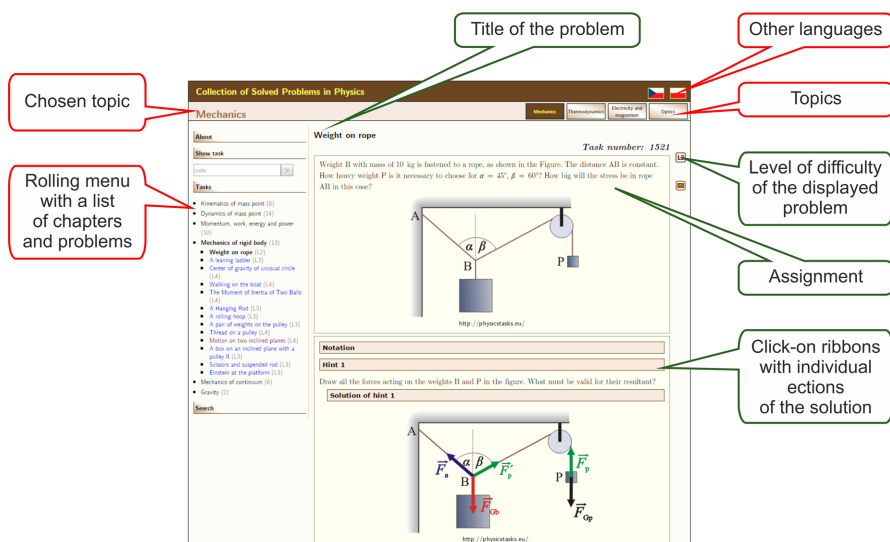


Fig. 1. Appearance of the Collection.

2 What the Collections look like

The user and administration interfaces of the Collections were remade to accommodate various features in spring 2015. These consisted of enlarged content, an additional branch (math problems), higher requirements on sorting and searching of problems, and contemporary web technologies.

Currently, a page with a task or experiment is divided into several parts (see fig. 1). At the top of the page there are headings and tabs to choose language, subject and topic. A drop-down menu with tasks and experiments from the chosen topic—physics or maths—can be found on the left side of the page arranged in chapters and subchapters. The problem or experiment itself is located in the main part of the web page.

Banners with individual sections corresponding to the problem solution or experiment description are placed under the title and problem assignment. By default, the content of sections is hidden for problems and visible for experiments, although its visibility can be toggled by clicking on the ribbon. This implementation ensures that the reader does not see the entire problem solution and is motivated by various hints to solve the problem actively. The Collection of Experiments uses the same structure of text divided into sections to keep the experiment description well-organized. The descriptions of experiments are supplemented by photo and video documentation as well as technical and pedagogical notes facilitating their performance. The readers can hide parts that they are not interested in.

The administrator interface is non-public and was designed with emphasis on the easy and time-efficient insertion of new problems and experiments into the Collections. The interface consists of several main parts. The first deals with the creation of a new problem or experiment; it includes the option to insert metadata about the addition, edit texts of assignments and sections and upload images (clips are stored in the separate YouTube channel). The second part of the administration interface provides tools for managing the Collection structure—for example, inserting problems and experiments into chapters or subchapters, or creating and modifying chapters' structure, as well as building new topics or branches in case of need. Finally the administration interface also contains a user management system and some supporting tools. Screenshots of the administrator interface are shown in Fig. 2.

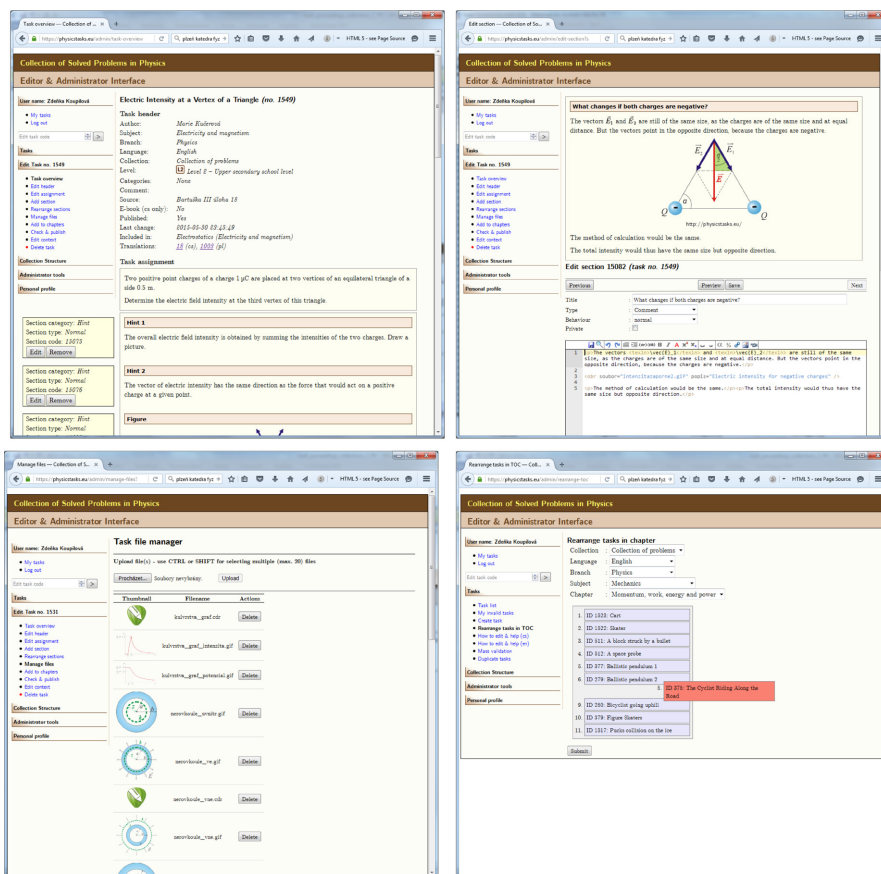


Fig. 2. Administration interface. Problem preview window (upper left), text editing window (upper right), file management window (lower left) and Collection structure changes (lower right).

3 Technical aspects of implementation

The Collection webpages are written in PHP5. All texts of problems and experiments are stored in MySQL database except for images and video. Texts of problems' sections are written in an extended version of XHTML using several special tags to format text and insert other objects (such as equations, images, links to other problems etc.). Formulas are written in LaTeX format and displayed by MathJax. Images are prepared in vector graphics editors (CorelDraw and Zoner Photo Studio mainly). Video clips are embedded using YouTube player.

4 Sorting, classification

Problems are classified into four levels according to difficulty: L1 – L4 (secondary school level, upper secondary school level, high school level and university level). The level of the problem is indicated by an icon in the upper right corner. Each problem can be included in special categories if it is solved using some special technique (e.g. qualitative problems, graphical problems, problems with unusual solutions, complex problems or theoretical problems). These special categories are indicated at the right side of the page as well. Currently, we are also preparing the option to sort problems according to the cognitive skills they are intended to develop. (Kürtiová A., 2014)

Language		Topics	Problems
Czech	Physics	Mechanics	208
		Electricity and magnetism	247
		Thermodynamics	136
		Optics	40
		Physics of microworld	62
		Theoretical mechanics	35
		Mathematical methods	80
	Maths	Mathematical analysis	162
		Linear algebra	149
		Algebra	14
English	Physics	Mechanics	50
		Thermodynamics	23
		Electricity and magnetism	52
		Optics	4
Polish	Physics	Mechanics	30
		Thermodynamics	25
		Electricity and magnetism	22
		Physics of microworld	12

Tab. 1. Numbers of published solved problems (December 2015).

Language	Topics	Published experiments	Experiments in preparation process
Czech	Mechanics	–	4
	Thermodynamics	34	10
	Electromagnetism	25	47
	Optics	13	14
English	Thermodynamics	2	9
	Electromagnetism	–	5
	Optics	3	1

Tab. 2. Numbers of published experiments and experiments in preparation process (December 2015).



Fig. 3. Number of unique visitors per day (all Collections and languages together).

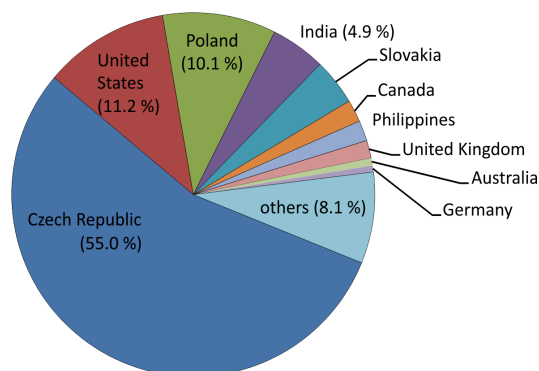


Fig. 4. Geographical distribution of visitors from January 2014 to June 2015 (all Collections and languages together).

Implementing the classification of experiments is planned as well. The experiment categories should include equipment demands, as well as experiment goals and duration.

5 Current contents

At the moment, the Czech portion of the database contains about 750 problems in physics and 350 problems in mathematics. The rest of the database contains more than one hundred physics problems in Polish and more than 120 physics problems translated into English (see table 1). All problems have structured solutions with hints and comments. Similar problems are linked to each other. We are continuing to prepare new problems for publication to cover all topics at all levels.

In addition to the above, there are about 70 experiments in Czech and 5 translated into English in the Collection of Experiments in Physics. As you can see in table 2, many new experiments are under preparation and will be published shortly.

The same technical solution for both databases challenges us to connect problems and experiments. A theoretical problem whose solution can be verified by experiment should be linked to the corresponding experiment and vice versa. The intention is to make it easier for teachers to use problems and experiments together. The Collections already include a few linked pairs of problems and experiments.

6 Objectives and Assessment

We have had very positive responses from users in the Czech Republic and beyond. Since 2013 we have used Google Analytics Tools to monitor web attendance. From January 2014 to June 2015, the Collections together had about 1000 unique visits per day (excluding weekends and school holidays)—as shown in Fig. 3. Also of interesting is the demographic distribution of users shown in fig. 4. This distribution shows that although the English and Polish parts of the Collection do not contain many problems and experiments, they are used regularly by many people.

7 Summary

On the basis of user feedback and web-visit counts we are convinced that both the Collection of Solved Problems as well as the Collection of Experiments in Physics are useful projects. They are still being developed and new components will be integrated. The Collection of Solved Problems is aimed at students and the Collection of Experiments in Physics is aimed at teachers. Fig. 3 (the number of visitors per day) shows us that we are reaching our target audience of teachers and students. Nevertheless, both Collections are public and open to everyone.

The Collections are available at the following websites:

<http://www.physicstasks.eu/>

<http://reseneulohy.cz/>

<http://fyzikalnipokusy.cz/>

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Learning Particle Physics Using Timepix-Based Pixel Detectors at CERN S’Cool LAB

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S’Cool LAB¹ is an international out-of-school hands-on learning laboratory at CERN. At S’Cool LAB, high-school students work with high-tech equipment to independently perform modern physics experiments that are linked to the technology and physics of CERN. Among the S’Cool LAB equipment is the MX-10 particle camera, which uses the Timepix chip as part of its hybrid pixel detector. This chip was developed by the Medipix2 Collaboration², hosted at CERN, and the detector as a whole has now been re-purposed for students by JABLOTRON ALARMS a.s.³. One goal of S’Cool LAB is to integrate this pixel detector into hands-on workshops and to evaluate its educational potential while taking into account students’ conceptions about radiation. Here, we introduce S’Cool LAB and the pixel detector, give an overview of possible experiments, and explain in more detail the current use of the detector in S’Cool LAB.

1 S’Cool LAB

S’Cool LAB is an international hands-on particle physics learning laboratory at CERN, Geneva, Switzerland. It aims to provide insight into the working methods, technology, and research of the world’s largest particle physics laboratory and to make the physics and technology of CERN understandable for students through hands-on experimentation (Figure 1).

The main target group of this out-of-school learning place is high-school students (ages 16-19) who come from all around the world to visit CERN. In addition to guided tours through CERN’s research facilities, selected student groups regularly take part in hands-on workshops in S’Cool LAB.

During these workshops, students work with high-tech equipment to perform modern physics experiments. All experiments are grouped into the categories particle acceleration, particle detection, and applications of particle physics. Currently, a workshop consisting of three experiments is offered: Students first build their own particle detector (a diffusion cloud chamber based on dry ice and Isopropanol) and observe tracks of cosmic particles and natural radiation. Afterwards, students study particle acceleration using an electron gun and learn about electrically charged particles in electric and magnetic fields – prerequisite knowledge to understand particle accelerators and colliders like the LHC (Large Hadron Collider) at CERN. Furthermore, students work with X-ray machines and the MX-10 pixel detectors to learn about the interactions of photons with matter and thereby gain insight into applications of particle physics in our every-day life such as medical imaging in hospitals, for example.

1 Homepage of CERN S’Cool LAB <http://cern.ch/s-cool-lab>

2 Homepage of Medipix Collaboration <http://cern.ch/medipix>

3 Homepage of JABLOTRON ALARMS <http://www.jablotron.com>



Fig. 1. S'Cool LAB - a hands-on particle physics learning laboratory at CERN.

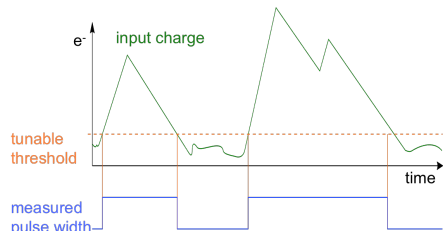


Fig. 3. Illustration of the energy measurement mode of Timepix. The time period in which the input charge stays above the threshold setting is proportional to the deposited energy.

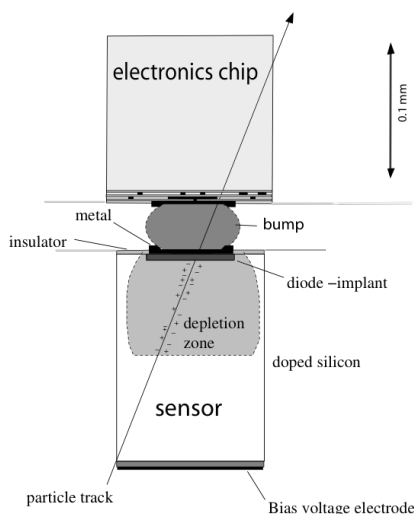


Fig. 2. Cross section through one pixel of a hybrid pixel detector with a particle track (reprint from Rossi, 2006).

S'Cool LAB not only serves as a learning opportunity for students, but also as a test bed for physics education research. Research on students' conceptions about modern physics is of particular interest. All activities in S'Cool LAB have been developed in an iterative design process taking into account students' interests and conceptions, physics curricula, and aspects of CERN physics and technology.

2 Hybrid Pixel Detectors

Among S'Cool LAB's equipment is a hybrid pixel detector that uses the Timepix chip. The Timepix chip was developed by the Medipix2 Collaboration, hosted at CERN, and the detector as a whole was re-purposed for high-school students by JABLOTRON ALARMS a.s. in the MX-10 particle camera.

Hybrid pixel detectors consist of two layers. One part is a pixelated, semi-conducting sensor material, where ionising radiation deposits certain amounts of energy depending on the path and momentum of the particles while traversing the material. This energy can be measured through ionisation processes in the semi-conducting material with an array of charge-sensitive amplifiers in a readout chip. The readout chip represents the second layer and is segmented into the same number of pixels. The two layers are connected one by one to the corresponding pixels of the sensor via solder bumps as shown in Figure 2.

2.1 The Timepix Electronics Chip Series

The original purpose of the detector chips developed in the Medipix Collaboration that started in 1999 was medical imaging, hence its name. This technology transfer effort from detectors for particle physics to medical applications resulted in a pixel detector readout chip series called Timepix (Llopart, 2007). In addition to counting photons in a defined measurement period (Medipix mode), the pixels can be alternatively configured to measure the deposited energy or the arrival time of an event. The sensitive area measures $1.4 \times 1.4 \text{ cm}^2$ and hosts 256×256 pixels, which results in a size of $55 \times 55 \mu\text{m}^2$ per pixel. Depending on the sensor and the bonding process, a certain minimal energy sensitivity of

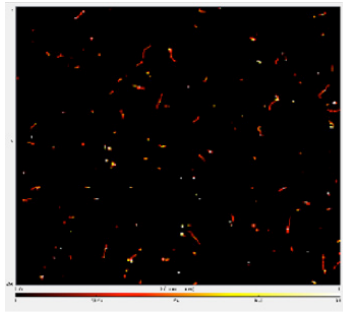


Fig. 4. Screenshot of a background measurement (35 min) with an MX-10 pixel detector and Pixelman software. The colour map represents the amount of energy.

a hybrid pixel detector assembly is achieved per pixel. The energy calibration of the MX-10 particle cameras used in S'Cool LAB results in a lower threshold setting of 5 keV, providing a very sensitive measurement tool for a wide range of experiments.

2.2 Detection Principle

The energy deposited by ionising radiation frees electron-hole pairs in the depletion zone of one or multiple pixels in the sensor material (made of silicon in the case of the MX-10). Electrons or holes are collected through an externally applied electrical field, converted into voltage pulses and digitized by Timepix. Depending on the sensor type, either electrons or holes are converted. In energy mode, the duration of a voltage pulse above the threshold level is measured per pixel as shown in Figure 3 and transmitted from the MX-10 via USB to a computer. After calibrating every pixel with the known energy spectra of radioactive sources, the deposited energy can be calculated based on the measured pulse width. The typical energy range for Timepix pixels spans from the threshold setting up to several MeV.

3 Learning With MX-10 Pixel Detectors in S'Cool LAB Workshops

Pixel detectors can be used as a versatile tool not only in particle physics research or medical imaging but also in physics education. If the detectors are refurbished in a compact way and accompanied with a simple analysis software, students can use them to perform a wide range of measurements with background radiation or radioactive sources, as demonstrated previously by Whyntie et al. (2015).

3.1 Examples of Possible Experiments Tested With the MX-10 Detector

3.1.1 Background Radiation

Students can study tracks of particles originating from space or from naturally occurring radioactive isotopes in real-time. Different types of particles are distinguished by the specific signature recorded with the detector (Bouchami et al., 2011). A screenshot of a background measurement (35 minutes) using the Pixelman software⁴ is shown in Figure 4. A pattern recognition algorithm associates straight tracks with muon candidates (Figure 5), curly tracks with beta candidates (Figure 6), heavy blobs with alpha candidates (Figure 7), and dot-like shapes with gamma candidates (Figure 8).

In addition to pattern recognition, the software can be used to display the energy information of single tracks or to produce histograms of the energy distribution of the different types of particles.

⁴ Homepage of Pixelman software <http://www.aladdin.utef.cvut.cz/ofat/Pixelman>

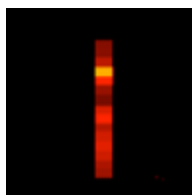


Fig. 5. Snapshot of “straight track” shape (muon candidate).



Fig. 6. Snapshot of “curly track” shape (beta candidate).

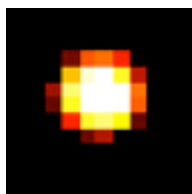


Fig. 7. Snapshot of “heavy blob” shape (alpha candidate).

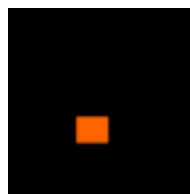


Fig. 8. Snapshot of “dot” shape (gamma candidate).

3.1.2 Properties of Ionising Radiation

Students can use the detector to verify the inverse square law (Figure 9), study the attenuation of ionising radiation in matter, determine emission energy spectra of radioactive sources, and examine slightly radioactive every-day objects like thoriated tungsten rods (Figure 10).

3.1.3 X-Ray Imaging

Combining the MX-10 detector with an X-Ray source, students can use the detector as an on-line X-ray camera. Objects like insects or memory cards can be X-rayed and the variable absorption of photons in the material results in a radiograph (Figure 11). In addition to imaging, energy spectra of the X-Ray source can be measured at different acceleration voltages (Figure 12).

3.2 Students' Conceptions About Radiation

“For museum professionals, knowledge of the audience’s conceptions of the issue to be presented in an exhibition should always be considered in the exhibition development process, and it should be noted that the audience’s conceptions may prevent the intended interpretation of information presented at a museum.” (Henriksen & Jorde, 2001)

Awareness of students’ conceptions is essential not only for museums (Henriksen & Jorde, 2001) but also for out-of-school learning places, including S’Cool LAB. Indeed, knowing students’ conceptions about the underlying physics concepts is needed to successfully design learning activities with hands-on experiments and to foster understanding. Measuring particle properties using pixel detectors naturally builds on students’ conceptions about radioactivity and radiation. Previous studies investigated students’ understanding of ionising radiation and associated concepts like radioactivity, irradiation or contamination (Figure 13).

In addition to a general lack of distinction between these different concepts among students (Millar, Klaassen, & Eijkelhof, 1990), it has been shown that radiation is perceived as dangerous, especially if the source is artificial (Eijkelhof, Klaassen, Lijnse, & Scholte, 1990). An exception is the use of ionising radiation in hospitals: In this context students consider radiation safe (Millar, 1994). Several other students’ conceptions about different aspects

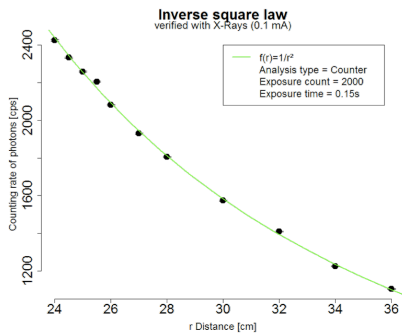


Fig. 9. Inverse square law.

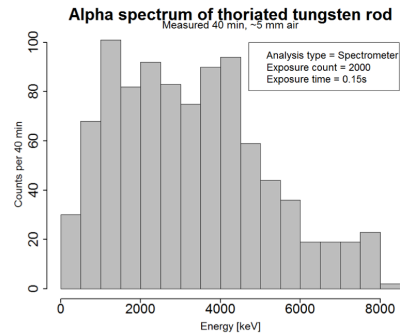


Fig. 10. Alpha spectrum of thoriated tungsten rod.

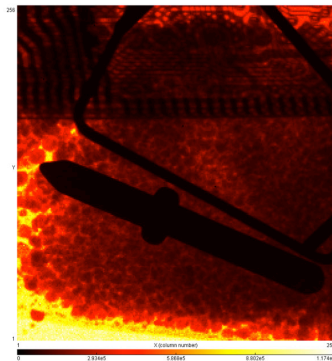


Fig. 11. Radiograph (solder pin, staples, salt grains, and memory card).

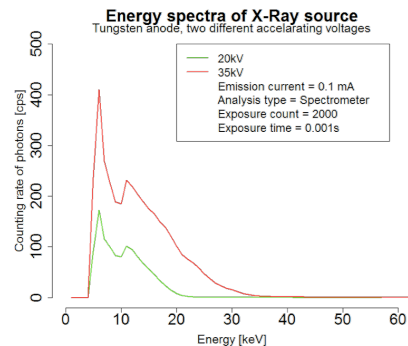


Fig. 12. Energy spectra of an X-Ray source (tungsten anode).

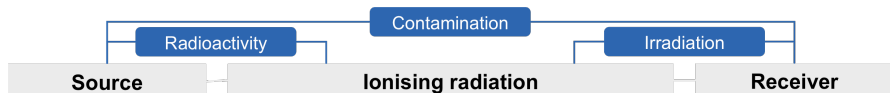


Fig. 13. Concepts associated with ionising radiation (Millar, Klaassen, & Eijkelhof, 1990).

of radiation have been studied so far; of interest for S'Cool LAB are especially conceptions that can be explicitly addressed during a workshop, e. g.:

- “After irradiation with X-rays, objects become radioactive themselves.” (Eijkelhof, Klaassen, Lijnse, & Scholte, 1990)
- “The transparency of material is the same for X-rays as for visible light.” (Clément & Fisseux, 1999)
- “Ionising radiation is deflected by a screen like visible light.” (Riesch & Westphal, 1975)

Many of the misconceptions reported by previous studies have one thing in common: Students “do not have a secure understanding of the particulate model of matter” and therefore show “sever difficulties with the atomic and sub-atomic level explanation of radioactive phenomena” (Klaassen, Eijkelhof, & Lijnse, 1990). This suggests that learning about the properties of different particles and their interactions with matter could possibly reduce known misconceptions among students. Workshops in S'Cool LAB try to assess students' misconceptions and to confront students with unexpected observations through the use of Prediction-Observation-Explanation tasks.

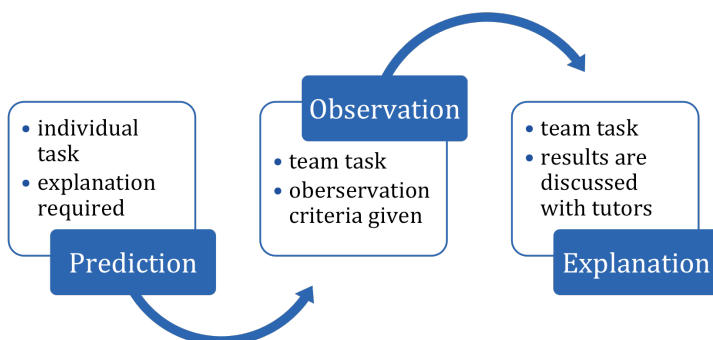


Fig. 14. Prediction-Observation-Explanation cycle in S'Cool LAB.

3.3 Prediction-Observation-Explanation (POE) Tasks and Students' Conceptions

3.3.1 Prediction-Observation-Explanation (POE) Tasks in S'Cool LAB

Prediction-Observation-Explanation (POE) Tasks (White & Gunstone, 1992) are an integral component of learning activities in S'Cool LAB to

- assess students' conceptions about the phenomena they are studying, and
- to promote conceptual learning during experimentation.

The schematic flowchart of the use of POE tasks in S'Cool LAB is shown in Figure 14.

First, students are asked to predict the outcome of an experiment and explain their reasoning. To cognitively activate all students and prevent social loafing, this step is designed as an individual task. The experiments are constructed in such a way that students will predict the outcome incorrectly – if they hold certain misconceptions – and be surprised by the outcome. By asking the students to explain their reasoning, students' conceptions can be assessed in this step (Liew & Treagust, 1998). In a second step, students perform the experiment in a team and observe the outcome carefully, based on given observation criteria. Depending on the students' initial prediction, the outcome might bring their misconceptions to their attention and unravel inconsistencies in their reasoning. Finally, students discuss differences between prediction and observation within the team and with the help of tutors, to explain the experiment and to promote a better understanding of the underlying concepts.

3.3.2 Example of a POE Task in S'Cool LAB – Irradiation vs. Contamination

To probe whether students fail to distinguish between the concepts of irradiation and contamination as suggested by Eijkelhof, Klaassen, Lijnse, & Scholte (1990) a corresponding POE task is used in S'Cool LAB workshops: students irradiate salt and measure whether it becomes radioactive using pixel detectors by comparing three consecutive measurements (see Figure 15). Before they start the experiment, students predict the outcome based on their previous knowledge.

After analysing student worksheets of 86 students who participated in S'Cool LAB workshops between September and December 2015, 63% of the students' predictions show misconceptions about X-radiation (Table 1). Students apply matter-like properties instead of process properties to radiation and consider radiation as something that “*salt takes up*” or “*is absorbed*”, which would result in additional particles originating from salt after irradiation. This reasoning was documented in findings by Eijkelhof, Klaassen, Lijnse, & Scholte (1990). Some students think that “*X-rays can make salt unstable*” and salt would therefore become radioactive. Only 21% of the students predict correctly that there would be approximately the same number of particles in measurements A and C. 16% of the students neglect background radiation completely and predict no particles in both measurements.

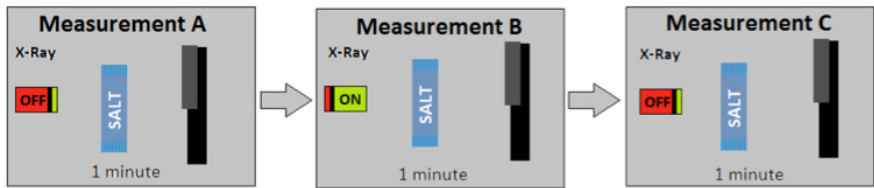


Fig. 15. Measurement schedule for POE task “Irradiation vs. Contamination” in S’Cool LAB. Students are asked to compare the number of particles measured by a pixel detector in A and in C.

The detector will measure...	Prediction (N=86)	Example for students’ explanations of their prediction	Observation (N=81)
... more particles in C than in A	43%	“Salt takes up radiation.” “X-rays can make salt unstable.” “Radiation from B is still present.”	28%
... approx. the same number of particles in C and A	21%	“Salt does not radiate, stores no X-radiation.”	36%
... fewer particles in C than in A	20%	“Salt blocks.” “Salt absorbs the X-rays.”	22%
... no particles in C or A	16%		14%

Tab. 3. Students’ predictions including example explanations and their observations.

After performing the experiment, only 36% of the students observe the outcome correctly and do not report a difference between measurements A and C. They seem to adapt their theories, resulting in explanations like “Photons are consumed in the same way as for normal light: If the light is off, there are no photons” or “Radiation doesn’t stay within the chamber after it is switched off”. 14% of the students report no particles, neither in A nor in C. This might be explained by software problems or by a very low number of particles from background radiation during the measurement.

In summary, students’ predictions and explanations show poor knowledge and a lack of distinction between the concepts of irradiation and contamination, consistent with previous findings. Rather detailed instructions in student worksheets and guidance by tutors does not guarantee that students observe and interpret experiments correctly. Instead, students’ observations and also their reasoning seem to be influenced by stable misconceptions. Findings from Miller, Lasry, Chu, & Mazur (2013) support this assumption: They found that even for demonstration experiments in university lectures, only 85% of students report the observation of an experiment correctly. Their findings also underline the importance of correct observations for conceptual learning and suggest that students make more correct observations when working with POE tasks.

In the future, student worksheets and the experiments in S’Cool LAB will be further developed to increase the number of correct observations, e.g. by longer measurement times and therefore clearer results. In addition, learning in S’Cool LAB workshops will be measured quantitatively using a concept test.

4 Conclusion

Pixel detectors are versatile research tools, not only in particle physics but also in physics education. Students can study single particles’ properties in a very accurate way but also use them as on-line particle cameras. The POE task described in chapter 3.3.2 shows one example of how pixel detectors are currently used in S’Cool LAB workshops. Although this task might not exploit the full potential of the detector, it shows the potential of POE

tasks assessing students' understanding and reasoning when working with the detector. The POE task also shows that support from tutors is essential for students when performing and interpreting an experiment when the physics background is new to the students.

We believe that the visual and real-time measurement of particles through pixel detectors has the potential to improve students' understanding of the particulate nature of radiation and can thereby help to reduce misconceptions among students. Results from the observation and explanation steps already suggest that students can learn about radiation in this environment. Currently, a concept test based on findings from the POE tasks is under development and will be used before and after workshops to measure conceptual learning in S'Cool LAB.

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MULTIMEDIA IN TEACHING IN LEARNING QUANTUM PHYSICS

Julien Bobroff, Frédéric Bouquet and Camille Jutant
New Ways to Reimagine Quantum Physics
by Bridging the Gap Between Teaching and Outreach..... 75

**New Ways to Reimagine Quantum Physics
by Bridging the Gap Between Teaching and Outreach**

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We have developed different tools to reimagine quantum physics representations in teaching and outreach. We first describe the “Quantum Made Simple” project, a set of graphic animations, which display basic quantum phenomena in a coherent graphical language. We discuss the design choices we made and why teachers, researchers, or laymen should eventually use these animations. We then present “Quantum Design”, a collaborative project with designers to engage the general public with quantum metaphors. We discuss why these projects are hard to classify into categories a spectrum ranging from education to outreach and even art. These boundaries raise questions regarding how the fields of design, outreach and education sometimes overlap. We propose that this inter-disciplinary approach may help to provide new ways to present fundamental physics to the general public and also to the students.

1 Introduction

In the academic world, students encounter quantum physics sometimes at the end of high school in scientific sections and then in undergraduate physics courses in university. It is often taught in a traditional format combining formal courses and training exercises. Recently, a large community of physicists and science education researchers have used new technological tools to reimagine this teaching, developing simulations, remote or virtual labs, interactive screens, new visualizations or online environments (see for example the two sessions about quantum physics in the *Multimedia in Physics Teaching and Learning 2015 conference*).

Similar evolution has occurred in the field of outreach and informal science. Quantum physics is still being presented in traditional formats such as popular talks, books, articles or TV documentaries. The past ten years, however, have seen new formats and media emerge (Masserant, 2014) including short, engaging talks like Ted conferences, new types of videos like the Youtube channels Minute Physics or Veritasium, serious games (Lieberoth, 2015), new print formats, and finally artifacts (various types of creations) involving art or design (Bobroff, 2014).

Surprisingly, these evolutions in the education and outreach fields have occurred in parallel with no strong overlap. In fact, respective objectives, target audiences and prescribers are different and should not be confused. But a dialog and best-practices exchange between the fields of education and outreach could be mutually beneficial. Teaching could benefit from the strategies deployed in the outreach world on how to engage and captivate an audience. Likewise, outreach could benefit from the academic approaches in terms of scientific content and education tools, especially on more advanced topics, which are usu-

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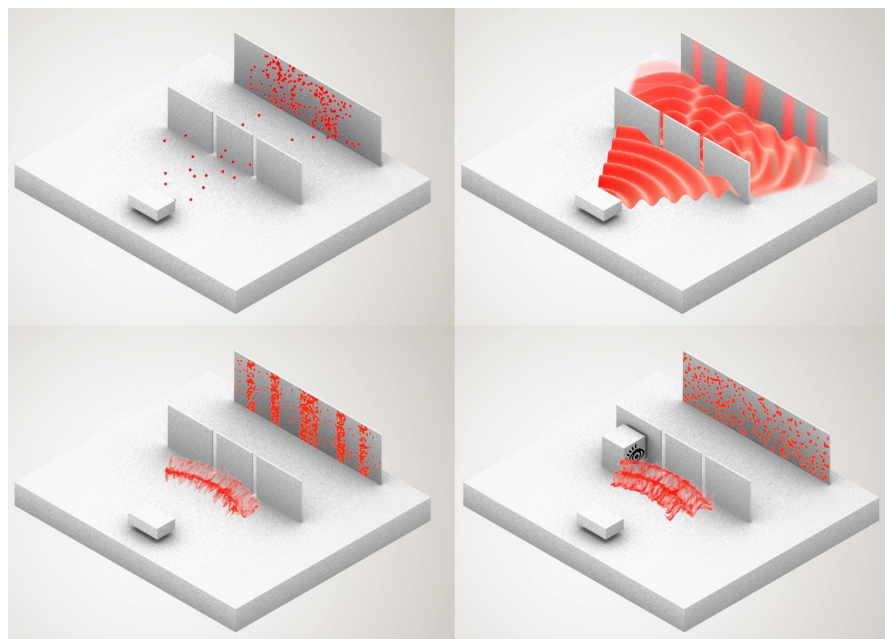


Fig. 1. Screenshots of the double slit experiment animation, displaying 1) particles 2) waves 3) quantum wave functions and 4) the same with an observer at one of the two slits (resulting in the destruction of the interference pattern) (full animation available at <http://www.QuantumMadeSimple.com>)

ally not even addressed by the outreach community. In addition, the academic world is not operating in isolation: physics students also use outreach resources in parallel with their courses, and may find it hard to reconcile these two points of view on the very same topics.

In this article we describe some collaborations where teachers and researchers from the academic world collaborate with outreach specialists, designers, illustrators and graphic designers to create innovative media about quantum physics (Bobroff, 2013). We focus on two typical examples of this process: first, a set of pedagogical animations designed with graphic and web designers, and secondly, a set of artifacts (design objects, devices, videos, books...) conceived with designers to make the quantum world more tangible and appealing. We will also discuss how these productions compare to more conventional outreach or teaching approaches and how they were used in both outreach and education contexts. This illustrates how bridges can be built between the outreach and education fields.

2 Quantum physics animations: the “Quantum Made Simple” project

In 2012, quantum physics was introduced in the French official curricula for scientific courses in the last year of high school (Lautesse, 2015). During training sessions organized in our lab, physics teachers complained about the lack of simple visual tools to depict basic quantum phenomena in a consistent way. We therefore decided to create the “Quantum Made Simple” project to address this need (accessible at www.QuantumMadeSimple.com).

The “Quantum Made Simple” project consists of a set of thirteen pedagogical animations in 3D about quantum physics provided in a website as well as a Youtube channel and used in various Wikipedia articles. These animations address both fundamental quantum properties (e.g. duality, quantization, spin, tunneling, etc.) and more recent research topics (e.g. graphene, decoherence, etc.) or research techniques (e.g. photoemission, pump-probe techniques, crystallography, etc.). The animations were developed thanks to a collabora-

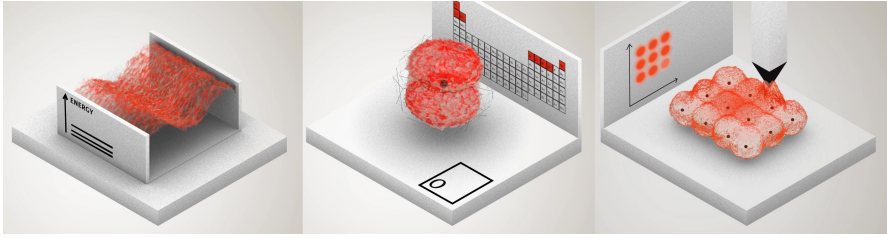


Fig. 2. Wave function representations in three different animations displaying 1) quantization in a box 2) atomic orbitals 3) scanning tunneling microscope (full animations available at <http://www.QuantumMadeSimple.com>).

tion between physicists from our university - researchers in condensed matter, optics, atomic and quantum physics - and graphic, web and sound designers (the DaFox agency).

Figure 1 shows a typical example, the animation of a double-slit experiment, which demonstrates the wave-particle duality. To represent the wave function, we chose red matter that behaves like a wave, but which is textured. This illustration helps to explain the difference between standard waves and particles. In order to ensure consistency between animations, the same red matter was used for wave functions in all contexts, as shown in figure 1 and figure 2: a free moving electron in a double-slit experiment, an orbital in an atom, or metallic delocalized electrons in a metal. The animations are displayed in an isometric framework. The horizontal plane is the basis for the quantum phenomena while vertical planes display physics measurements or mathematical spaces (energy levels, periodic table, STM imaging, reciprocal space...). They last from one to two minutes and are accompanied by a light subtitled legend. On the scientific side, the animations were not computed from exact simulations and do not represent rigorous treatments of quantum physics. They were developed as an easy-to-understand approximation of quantum phenomena for outreach. However, each animation was conceived with physicists who tried to be as accurate as possible, given the graphic constraints of representation and duration. For each animation, many round trips between the designers and the physicists were necessary. For each topic, an expert in the field of interest was included in the creation process. For example, David Clement, a physicist working on Bose-Einstein Condensation (BEC) in Alain Aspect's team participated to the conception of the BEC animation. After two years of use by various physicists all around the world, no major criticisms about the chosen representations were received.

As far as dissemination is concerned, all animations are gathered in a website with additional small articles introducing each effect, its applications and its use in recent fundamental research. (For example, the tunneling effect is used in both tunneling microscopes in fundamental physics and in electronic components for flash memory in industry.) Download is available in high resolution with captions in French, in English, or with no caption in case the explainer wants to develop their own oral support. Animations are also available on YouTube and in the sharing site www.commonswikimedia.org under a creative commons license —which allows anyone to copy, redistribute, remix or transform the videos. They were incorporated in about thirty articles in the French and English versions of Wikipedia (see, for example, the entries “laser”, “atomic orbital”, “quantum decoherence”, “Scanning tunneling microscope”, etc.). The animations were broadcasted to physics teachers through specialized Internet forums, talks in teachers' conferences, teachers' trainings, Wikipedia and by word of mouth. Beyond teachers, the animations are now used in science museums (for example in an exhibit about quantum physics at the Science Museum of Virginia), in outreach talks, in popular science websites (for example futura-science.com), in science festivals (for example the World Science Festival in New York) and in the media. More surprising, they are also used for teaching quantum physics at university, usually

as an accompanying visualization to a more formal approach (for example at Ecole Polytechnique in France or Aarhus University in Denmark). We even found out that a French textbook at undergraduate level uses snapshots of these animations to explain quantum phenomena, such as the electron band formation in a metal (Ribeyre, 2014). These were a-posteriori and unexpected uses of these animations.

In terms of audience, the QuantumMadeSimple.com website has had about 60 000 visitors this year, and the more successful animations were seen about 20 000 to 45 000 times each on Youtube. The largest audience, however, was probably reached with Wikipedia's articles displaying the animations even though it is hard to assess quantitatively. As an example, the "laser" English Wikipedia article is visited about 700.000 times per year.

From informal feedback over the past two years, we attribute this success to practical and design reasons. From a practical perspective, various users said that the animations were convenient because they were easy to download, available with and without legends, displayed no introductory credit panels or embedded logos, and were not too long.

On the design side, cognitive studies have tried to establish what the ingredients are for an animation to be effective (Wouters, 2008). First, contrary to conventional wisdom, dynamical animations are not necessarily superior to static graphics for learning (Lowe, 2003; Tversky, 2002). Mayer's cognitive theory of multimedia learning further shows that information is processed verbally (spoken and written) and non-verbally (pictorial) (Mayer 2001) and the two add positively. Thus, a verbal accompaniment to the animations is a key feature for pedagogy, when a supportive pedagogical agent guides the students and provides explanations (Wouters, 2008 and ref. therein). These cognitive studies imply that our quantum animations are not providing a sufficient pedagogical role alone, for example when being seen on Youtube by individuals. They are likely to be more effective when used by a teacher in his course or by a scientist in an outreach talk. Appearance and graphic design are also crucial as has been stressed in studies on both cognition (Shah, 2003; Weiss, 2002) and the science of communication (Bucchi, 2013). Whether it is called "cosmetic appeal" or "style", this aesthetic quality of the animations is often underestimated, and not easy to assess since it depends on the public and the on-going fashion. However, this notion of "nice looking animations" was often quoted as an important ingredient for the success of our animations, especially among the young adult audience.

These animations are at the frontier between education and outreach, both in their content and use in high schools, universities, science outreach centers and public events. They therefore have to be analyzed both by education, cognitive, and communication studies to tackle not only their pedagogical value but also their "engaging" nature.

3 Collaboration with designers: The "Quantum Design" project

While the former animations were more focused on the pedagogical side of outreach, we turn now to the other side of the spectrum, the "quantum design" project (accessible at www.designQuantique.fr). The "quantum design" project is the result of a collaboration between physicists and a French design school, ENSCI-Les Ateliers. The same partners had already undertaken a project about superconductivity (Bobroff, 2014a). After being introduced to quantum physics and having visited labs and discussed with physicists, design students were asked to produce artifacts and design projects but left with freedom to choose the format and purpose. The projects were supervised by professional designers in collaboration with the physicists. Contrary to usual collaborations between scientists and artists focusing on a specific technology or topic, this project explored a wide variety of formats (videos, devices, design objects, live animations, books, photos), subjects (basic phenomena and applications) and approaches (pedagogical, artistic, design-oriented). These productions offer a more intuitive, aesthetic and tangible approach to the quantum world, one that supplements the more pedagogical "Quantum Made Simple" animations.

A sociological and semiological study was carried out about this project's resulting

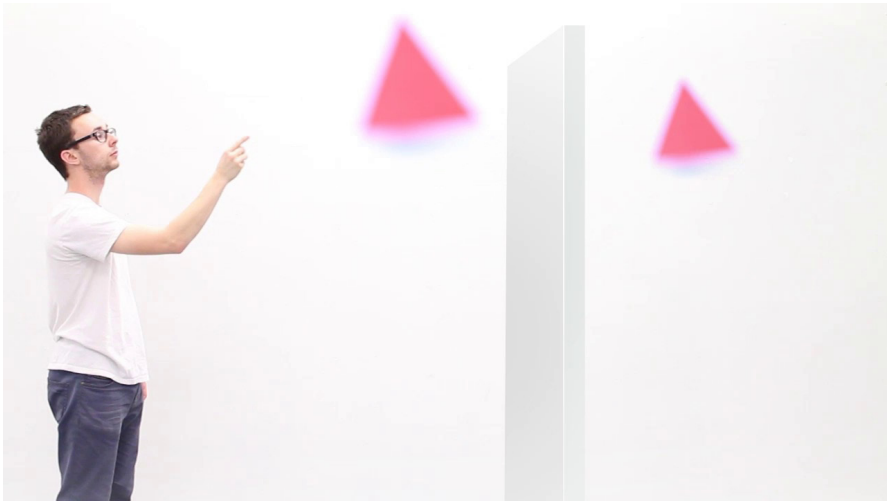


Fig. 3. Snapshot from the video “quantum thing” by the designer Paul Morin, which depicts a man manipulating large-size quantum wave functions, and in this image experimenting quantum tunneling.

artifacts (Jutant, 2015). It was based on a study of the creative process itself during the workshops, on interviews of the various actors (students, teachers, a physicist) and on the analysis of the artifacts. It revealed that the designers’ productions prompt reevaluation of not only the outreach contents but also the format and process of outreach itself. Indeed, we found that such collaborations produce new types of multimedia and outreach projects, both in their format, by the way they represent physical properties, and in the way they are presented to an audience.

Some projects exploit and question the scientific representation in pedagogical artifacts. For example, “quantum thing” consists of a set of videos, which show a man handling an animated form with blurred edges representing a quantum object, as shown in Fig.3. By simple manipulations, it is shown what wave collapse, tunneling, entanglement or quantization could look like at our scale.

Another family of projects investigates the construction of analogies between quantum physics and the everyday world. For example, the “quantum apartment” displays daily life situations based on quantum metaphors, for example a woman waters her plants, and her downstairs neighbor observes water leaking directly from the ceiling.

A third set of projects explores the communication medium itself. For example, the project “Tutu Quanta” is a demonstration setup used in front of the public by a mediator; a set of tools (cardboard sheets, plastic cubes, mirrors, ink, oil, bubbles) are used to perform small manipulations that illustrate the formal representations of different quantum properties, such as atomic orbitals or wave-function collapse. This demonstration setup is packaged in a box that evokes a small theater.

A fourth type of project investigates the relationship between art and science. For example, “an approach under influence” is a set of devices inspired by quantum physics but with no intention of pedagogy or outreach use: wallpapers, animated lights, children’s books, clothing, materials, containers, handbags...

These projects cover a full and continuous range from pedagogical tools to artistic or pure design objects in which it is difficult to draw a line between outreach, science and art. Even though these objects cannot be directly transferred into an academic framework, they help explore new types of visualizations and setups beyond the classical modes usually used for displaying physics.

4 Exploring new formats for outreach and teaching

In the past five years, we have developed many other outreach projects about quantum physics: folding activities, comic strips, postcards, experimental devices, websites, and videos... (accessible at www.PhysicsReimagined.com). All the projects involved collaboration between physicists and professional creative people (designers, illustrators, web designers, science explainers, artists...). These collaborations provided better insight into some potentially key ingredients for successful collaborative outreach or education projects. First, these collaborations are possible when physicists acknowledge their lack of expertise in design, graphics, web design or related areas. As an obvious consequence, these collaborations therefore imply a first stage of discovering each other's field of expertise. Time spent visiting each other's place of work in addition to small initial workshops without high expectations promotes discussion of respective skills and to ensure good relationships. Thereafter, the scenario and content of the production should not be unilaterally decided by the scientist alone but built with the designers, taking into account practical aspects. Designers must first get curious and engaged about the physics at play, forcing the scientists to find the proper explanatory tools and metaphors, which is both a constraint and an advantage of these collaborations. During the process of production, the scientist should clearly acknowledge its limits and not interfere with the design and aesthetic choices of the designer, provided the scientific meaning is not in question. Finally, from the outset of the project, strong emphasis should be placed on the future dissemination strategy, taking into account practical considerations such as formats, translations, logos, copyrights...

We want to stress a side-benefit of such design-science collaboration: these design and applied art schools have a long history in innovative project-based learning methods (Blumenfeld, 1991; Findeli, 2001). This inspired us to develop similar project-based courses in our own physics curricula. We created two new coursesteachings for third year physics undergraduates, one about outreach in physics and one about low-cost open-source tools for physics labs. Surveys could show their effectiveness in teaching physics differently (Bobroff, 2016; Bouquet, 2016).

In conclusion, this interdisciplinary production process helped us explore new types of media and designs to present quantum physics in a different light. We do not claim they should replace more traditional and rigorous approaches, but rather that they should be considered as one possible gateway to engage students with quantum physics. We also think that educators and teachers could learn a lot from designers and scientists about how to design efficient and engaging teaching media.

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TECHNOLOGY ENHANCED LEARNING AND TEACHER TRAINING

Sebastian Haase, Jürgen Kirstein and Volkhard Nordmeier

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The Technology Enhanced Textbook: An HTML5-based Online System for Authors, Teachers and Learners

Sebastian Haase, Jürgen Kirstein and Volkhard Nordmeier

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A great deal of multimedia content for physics education has been available for many years, ranging from simulations to interactive screen experiments to remote laboratories. Here we introduce a platform that enables authors to include these tools in self-contained, rich learning materials. Furthermore, the system supports personalized work experience and active learning for students. By eliminating the boundaries between authors and learners, the Technology Enhanced Textbook encourages students as well as teachers to adapt their learning materials to their individual requirements.

1 Background and Motivation

Current mobile media devices, such as smartphones and iOS or Android tablets already allow various forms of interaction with the physical and digital world beyond the usual communication-oriented functions of these devices. You can manipulate experiments, tools, texts, images and other media elements by intuitive touch gestures. Built-in or add-on sensors facilitate measurements and audio and video recordings. You can carry out discussions with other learners and experts or make content available via the Internet. By using GPS, image recognition or augmented reality solutions, location-based phenomena and objects can be identified and individually experienced through interactive experiments and additional multimedia information (Bryant, 2007).

Instead of defining learning in terms of the technical aspects of a learning environment, we believe that it is essential to encourage communication as well as active involvement with phenomena and learning objects to solve relevant problems. What role can digital media and web technology play in these kinds of settings? In order to enable individual knowledge construction we need a “*mediating*” device – a medium – for communication and learning. The German term “*mediengestütztes Lernen*” (media-supported learning) emphasizes that the media devices serve specific functions. In particular, they serve as tools to communicate and facilitate thought processes during learning (Neuhaus, 2011).

An exciting way to stimulate the learner’s curiosity is the use of interactive screen experiments (ISE) and interactive laboratories (ISL). These tools use actual photographs as photographic representations of real experiments and laboratories. They give learners the opportunity to virtually control an experiment and observe physics phenomena. Our group has been producing interactive screen experiments and interactive laboratories since 1996, and we have produced many CDs and DVDs to incorporate these products into useful learning materials (Kirstein, 2007). We have found that it has taken significantly more time and effort to produce the environment than what was required for the production of the ISEs themselves. Additionally, the ISE programming appeared to involve many repetitive steps. For this reason, a few years ago we decided to build a tool that would as-

Haase, S., Kirstein, J., & Nordmeier, V. (2016). The Technology Enhanced Textbook: An HTML5-based Online System for Authors, Teachers and Learners. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 85–92). Mulhouse: European Physical Society.

sist in writing and designing these learning environments, and we wanted to automate the ISE production as much as possible.

Today's worldwide coverage of interconnected multimedia technology is opening new opportunities to technologically enhance the traditional textbook. Our vision is a textbook – the „*Technology Enhanced Textbook (TET)*“ – that grows with the learner's experience. It is connected with the vision of an active learner who is the author and designer of their own personal textbook while going through the learning process (Neuhaus, 2013).

From 2010 to 2013 we had the opportunity to demonstrate and validate this vision in a project supported by the German “Bundesministerium für Bildung und Forschung” (BMBF). The aim of the project was to validate the potential for application of our research and to adapt our vision to the conditions of the market. Empirical data gained from focus group sessions with our partners in the educational field (schools, universities, educational publishers, museums, radio and television) and data from surveys that were answered by experts in the field of learning (teachers, students, lecturers) helped to outline the requirements for the TET. Three main pedagogical functions emerged during the focus group discussions. These were the basis for the concept and realization of tet.folio (Neuhaus, 2012):

- Toolbox function: Various sensors and technical interfaces are provided to measure, detect, experiment, photograph and record.
- Communications function: Learners communicate via chat or video call about their experiences and experiment together online.
- Portfolio function: Information can be researched and compiled from browsers, search engines and the cloud based TET-market, the virtual backbone of TET.

In an age of continuous innovation, e-learning seems to be too rigid. Numerous studies show that the expectations placed on e-learning are rarely met. Many concepts of e-learning are designed to make learning “easier” for students. However, learning is only effective when the learner actively solves problems and constructs knowledge in the process. Instead of trying to promote learning through simply clicking through items on the screen, our focus is on activities that use both the physical and virtual environments.

At Freie Universität Berlin we have used tet.folio in practical lab courses and educational multimedia courses (Mühlenbruch, 2016). tet.folio enables everyone to produce interactive multimedia content and share it with their peers. We hope that it will advance the open educational resources initiative by adding high quality content available to everyone.

2 Overview

The Technology Enhanced Textbook (TET) is an online platform for creating and working with interactive multi-media content (Kirstein, 2011). We call this platform tet.folio. All content is automatically saved in the tet.folio cloud and learning materials are organized into one's own personal e-portfolio. The learner or user of tet.folio is at the center of this learning environment; organizational and logistical functions are deliberately hidden so as to avoid distracting the student. Created content can be made accessible to everyone from everywhere if permissions are set accordingly. An export function helps in situations without Internet access and saves interactive, fully functional offline HTML files. Additionally it is possible to export individual pages or entire books as PDF files. tet.folio is a zero-installation web application (Software as a Service; SaaS) and runs entirely inside a web browser. It has been tested on Windows, Linux and Mac using Firefox, Chrome, Safari and Internet Explorer. The application is based on a newly developed design optimized for both desktop and mobile user experience. It runs on Android, iOS and Windows tablets. For very small screen sizes, as found on smartphones, a more responsive design is currently being developed.

3 Interactive Content Objects

tet.folio is structured like a library of books, metaphorically speaking. The portfolio is made up of books with pages, which in turn can be subdivided into chapters and sections. Pages

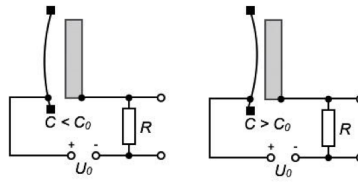


Fig. 1. An example of two images showing the minimum and maximum state of a capacitor microphone. If the tet.box that contains it is set to slideshow, the images get placed on top of one another, with only one showing at a time. Thus, the student can operate the device virtually, bending the diaphragm, by interactive clicking on the tet.box.

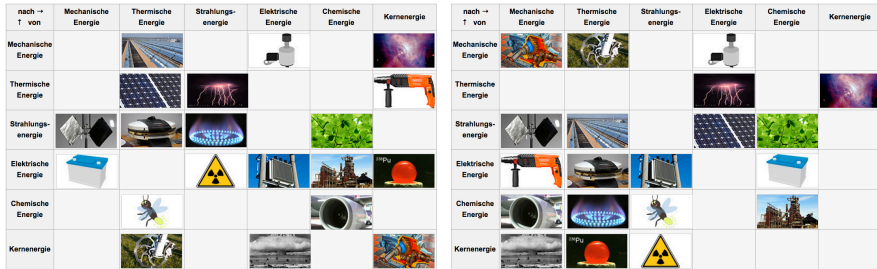


Fig. 2. A puzzle about the different means of energy transformation in daily life. The student can document their learning progress by moving the tiles from their starting places (left figure) to their correct places (right figure).

are created by adding media objects – for example, images, videos or text (content) boxes. These can be edited in-place directly on the page or in a full-featured editor with support for formatting and HTML5 source editing. Consistent styles across pages and books can be achieved using a stylesheet adapted specifically for the tet.folio system of CSS3 styles. All pages, books, boxes and styles are tet-objects that can be shared and are controlled by the tet.folio permissions system. Objects can be made readable or writable for individual users or for groups of users. In addition, page access for anonymous users can be restricted by IP address.

Images, videos and PDF files can be uploaded via drag & drop from the desktop of a computer. Furthermore, the built-in tet.cam tool directly accesses the device's photo camera and can upload newly taken images onto the current page.

Content boxes, called tet.bboxes, can also be nested and organized into a hierarchical order. This is useful for organizing layout, but becomes essential when using the interactive features of tet.folio.

Here are some examples on how authors can create different types of interactive learning activities. First there is the option to create a slide show. The author can place multiple objects (e.g. multiple images) into one container and display only one image at any given time. In this way, the student can peruse the images by clicking, thus an easy and effective way of showing the on and off state, or the before and after state, of an object is available (fig. 1). A second option is to create an interactive puzzle (fig. 2). The author can make objects "draggable" so that the student can click and move objects within the area given by the outer object. Objects can be made "magnetic", leading them to stick to the edge of other objects. A third option is to allow for labeling a diagram or picture of a complex device or scene. By making one-word-boxes draggable, the author can instruct the student to put them next to the corresponding part of an image. A fourth option allows for long-answer questions. Free-text boxes can be inserted, using the corresponding HTML component found in the editor's toolbar.

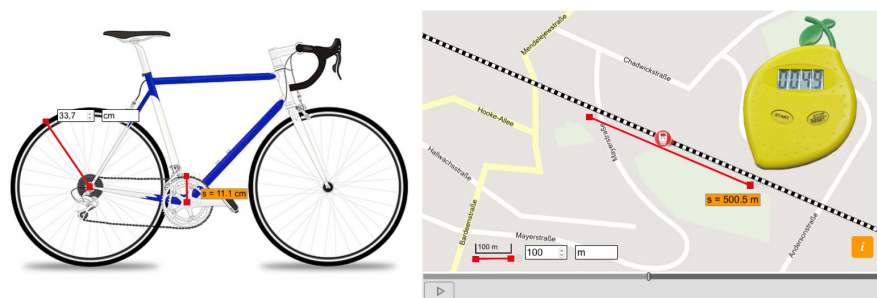


Fig. 3. Universal tet.tools can add extra learning activities to existing ISEs, images and videos. Here, the length tool is used to compare the radius of a bike's gear rim to its wheel radius. The same tool is used to measure the travel distance of a train, together with the stopwatch tool to measure the train's travel time in a video.

4 Personalized learning

Every student signed up for tet.folio compiles their own personalized collection of learning materials. When working with interactive elements, such as positioning a puzzle piece, the actions are saved automatically. Similarly, HTML input elements like checkboxes, radio buttons, and text fields save their state and values in a personalized manner. Furthermore, students can use any other tet.folio tool to make text notes by adding new text boxes or adding a photograph using the built-in tet.cam. These personalized additions are saved to a dedicated “transparent” layer owned by the student and do not otherwise interfere with the original content.

tet.folio also offers a full-featured drawing tool. This tet.board functionality is taken from the Open-Source project SVG-EDIT (Rusnak, 2009) and we have adapted it to fit into the tet.folio framework. As a result, this tool automatically saves every stroke to create a drawing layer of vector (SVG) graphics. Using this tool, the student can make personalized notes using the mouse or touch screen. In addition, it can also be used by the author or teacher to add graphical elements to the learning material itself.

5 tet.market

To encourage and assist in sharing learning materials, tet.folio comes with a built-in section called tet.market. With this market, whole books, individual pages, images, videos or interactive screen experiments can be made available to others. The tet.market can be used to share objects with individual users, a particular group or all users. The current implementation of this section is still rudimentary and is currently being updated. For example, there is no tagging functionality and it is not possible to filter learning materials by their license. While we would like to promote creative commons as the preferred license of sharing objects, it could also be possible to invite professional developers of teaching materials to offer their product on their own terms. The permission system together with the object oriented meta-tag database in tet.folio is able to technically support any of these scenarios.

6 tet.tools

Other types of objects found in the tet.market are tet.tools. These are text blocks containing graphics or logical code. A defining feature of these interactive tools is their modularity and universality. They can be added to any existing page to support interactive approaches to solving problems. For making measurements, the respective tet.tool can be placed above images, videos or ISEs (fig. 3). It is also possible for the author of a tet.tool to specify a number of configuration parameters allowing the author to adapt the tool to a specific context, e.g. labeling the x/y axes of graph plots.

Gyro-Sensor

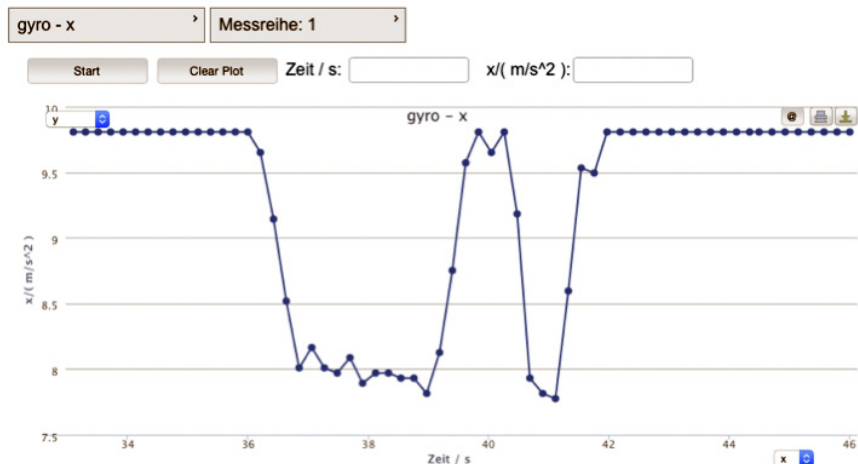


Fig. 4. HTML5 can read the gyro/acceleration sensor built into most smartphones. The tet.folio tool shows a measurement of the Earth's gravitational acceleration of about 9.8 m/s^2 . Slight tilting results in changes of the measured value over time.

Some of the interactive tet.tools include:

- A movable angle measurement tool
- A draggable line and polygon length measurement tool
- A polygon area measurement tool
- Interactive x-y-graph paper to add measurement points by clicking
- An auto-check button for fill-in-the-blanks problems using text containing “___”-parts
- A stopwatch

A key point to note is that all of this functionality can be added to pages without any programming knowledge. However, tet.folio also allows the authors to add more interactive functionality by writing their own raw JavaScript. For example, they can use the recently added HTML5 feature for accessing the built-in motion and gyro-sensor found in most smartphones and tablets. At MPTL'20 we presented an example page that directly plots measurements in an acceleration-time diagram (fig. 4).

7 Advanced Features

In addition to supporting authors in creating rich interactive content without programming, tet.folio also helps address more advanced tasks. It permits the writing of mathematical equations using the LaTeX markup language when enclosed in single or double dollar symbols. The mathematical expression generated is automatically adjusted in font-size and style to the surrounding text paragraph. Another feature of tet.folio is the use of variables. These are keywords enclosed in braces allowing the author to reference, for example, a page or book title, a page number, or an object ID to be used in JavaScript code. Using braces an internal database is accessed that supports automatic labeling and referencing of objects like figures and equations. These labels can be addressed across the entire book and numbers are automatically adjusted as new figures and equations are inserted.

In addition to the LaTeX mark-up and static variables, there is the tet.folio concept of dynamic variables: JavaScript snippets enclosed in `{* ... *}` can be directly written into the main text. These snippets are replaced by the results of the respective code and are updated as the student interacts with the page. The code itself can contain variable expres-

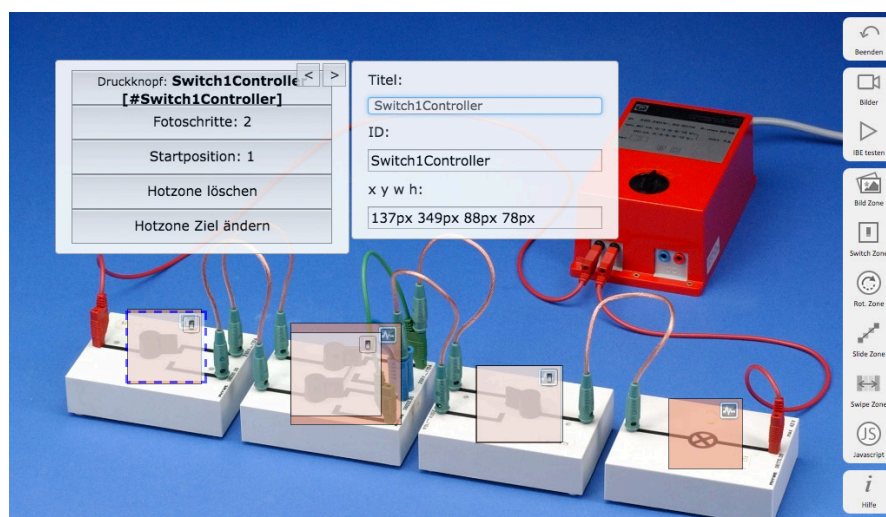


Fig. 5. tet.folio includes the ISE.maker, which turns a series of photos into an interactive screen experiment without requiring any programming experience. After defining interactive regions the user is asked to upload the respective photographs. The regions can be specified by clicking on the screen or by entering exact pixel coordinates.

sions referring to other object's content or attributes, such as their position. For example: an input text field in a tet.box named mynumber on a page could be referred to by another text block containing `{* 2*{mynumber.1} *}`. Consequently, the second block always shows twice the value entered by the student. (The "1" refers to the first input field in the tet.box named mynumber.) These dynamic variables can be used anywhere in the HTML code, even as part of a CSS style or SVG section, allowing interactive control of position, orientation and other styling aspects of objects.

8 Collaborative learning

Working in the tet.folio cloud also opens up new possibilities for interactive learning for student groups. The tet.room concept allows teachers to invite students into a dedicated tet.room. Members of this room can now see actions others are doing in real-time. This includes moving objects, switching from one page to another and working with an interactive screen experiment. Similarly, editing of free-text fields and drawing on the tet.board is immediately synchronized between tet.folio users and devices. This effectively turns any video projector into a digital white board when used together with a tablet or laptop.

Collaborative work presents another way to use real-time synchronization during the writing and designing of new content. This could either be a group of students working on a homework assignment or two or more teachers exchanging ideas on their newly developed screen experiments. The websocket technology used for this is part of the HTML5 standard. In order to run this, a second web-server that supports asynchronous HTTP calls is part of the tet.folio infrastructure.

9 ISE.maker

tet.folio has a built-in tool for turning a series of photos into an interactive screen experiment. The goal of this tool is to support the construction of basic ISEs without the need for any programming experience. This can be used by teachers preparing learning materials, as well as by students doing an assignment to document their experiments using an innovative and interactive medium. After uploading a reference background image, specific

regions in the experiment have to be defined. There are interactive regions assigned to certain modes of interaction: either clicking, sliding, or dialing. There are also image-changing regions where images are exchanged as a result of the student's interaction. After these two kinds of regions get connected and all needed images are uploaded, the ISE is ready to be used and is automatically added to one's tet.folio page. Image and interaction regions can be configured at any time. Positions and dimensions can be adjusted using the mouse or touch device, or can be entered into input fields for pixel-exact coordinates (fig. 5). The regions can also be given custom, meaningful names. The ISE.maker provides an advanced mode to enter custom JavaScript. Here, region names can be referred to and non-standard logic can be implemented to realize more complex ISEs. We are in the process of evaluating the limits and feasibility of this approach to unify all the ISEs produced in our lab. Once this is achieved, the remote control feature provided by the tet.room technology will be available to all of them. Similarly, future functions, such as interaction recording and interaction replay, will be universally accessible.

10 Summary and Outlook

tet.folio is designed to be a personalized application for mobile devices that can also be accessed via any computer web browser. The portfolio feature of tet.folio allows students to store personal externalized knowledge fragments, ISE, ISL, as well as individually collected web content. For this purpose, tet.folio is capable of storing content in an individually designed structure. Here, the focus is put on clean and intuitive handling, unlike the complicated functions often found in other learning management systems (LMS). In addition to providing each student with the opportunity to individually design content, teachers and publishers are also able to offer ready-to-use content that can be included in the individual portfolios of students. The portfolio function of tet.folio enables the tracking of individual knowledge construction regarding design and research processes, by reflecting personal development steps. All information available online can be integrated into the portfolio, including "Open Educational Resources" content, under the Creative Commons License, and paid media modules offered by publishers and knowledge brokers.

tet.folio is an online platform that assists both students and teachers in creating multimedia content without any prior programming knowledge. Using a comprehensive approach, tet.folio's aim is the embedding of multimedia into a learning environment that focuses on the learner. It is designed to be both flexible and easy to adapt to specific students and learning groups. Modern technologies, e.g. HTML5 and JavaScript, are used to implement universal learning tools that can be added to pages in a modular and transparent fashion. Collaborative learning and collaborative authoring allows for new and flexible approaches to working with the learning materials.

As such, tet.folio is a universal platform that could be used by the education community to incorporate existing content and make it directly accessible to teachers and students. One could imagine connecting the tet.market to databases that are already established and to media collections, such as compadre.org (Mason, ComPADRE) and PhET (Wieman, et.al. 2008). HTML5 and JavaScript have surpassed other formats such as Java-Applets and Flash, while still being flexible enough to satisfy any requirements of the physics teaching community.

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Integrating Simulations and Hands-on Activities in Physics Pre-service Teacher Education

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Simulations are a valuable tool in teaching modern science. We report on an experiment in a physics laboratory on electricity using both simulations as well as hands-on activities. The laboratory was implemented as part of a course for pre-service secondary school physics teachers. The 45 participants were divided into two groups, one performing first simulations and then hands-on activities, the other in the reversed order. The laboratory activities focused on DC circuits related to real-life situations, like a multiple socket or a chandelier modeled with simple wires, batteries and bulbs. The participants were asked to make predictions of the outcome before conducting each task and to compare their predictions with the observations and measurements they made during the activities. No significant differences in performance were observed between the two groups, suggesting that in this experiment simulations did not help the pre-service teachers in transferring their conceptual knowledge to practical application.

1 Introduction

Simulations have become a widely used tool in modern science education (Wieman, Adams, Loeblein, & Perkins, 2010). Numerous studies have investigated the impact of simulations on the learning process and outcomes, as well as their usefulness in various contexts of science education (Rutten, van Joolingen, & van der Veen, 2012). It has been established on various occasions that the use of simulations enhances the motivation and performance of students (Finkelstein et al., 2005; Wieman, Adams, & Perkins, 2008; Zacharia, & Anderson, 2003).

Given the advantage of incorporating simulations into today's school science curriculum, it is particularly important to introduce future school teachers to these tools during their pre-service education (Chittleborough, 2014). Making simulations part of teacher education and discussing experiences related to pre-service training offers future teachers an opportunity to experience the benefit of simulations from the students' point of view.

An important part of adapting simulations to science teaching is their relationship to hands-on experiences in educational laboratories. In order to investigate this matter, we offered a laboratory on electricity, integrating hands-on activities and simulations as part of a teacher training course for pre-service mathematics and physics secondary school teachers. The choice of electricity was motivated by the fact that this subject is usually difficult to teach for initial service teachers (Furió, Guisasola, Almodí, & Ceberio, 2003), especially for those who graduated in mathematics. Probably due to a lack of practical experience, it is often observed that the understanding of the electromagnetic ideas lacks sufficient depth in these areas.

The laboratory experience provided the pre-service teachers an opportunity to experiment and reflect upon both kinds of learning environments, simulations and hands-on activities.

Hemmer, S., Moretto, S., & Pantano, O. (2016). Integrating Simulations and Hands-on Activities in Physics Pre-service Teacher Education. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 93–99). Mulhouse: European Physical Society.

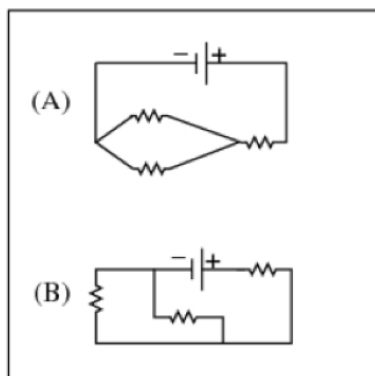


Fig. 1. Circuits corresponding to question Q8 of the pre-test.

Furthermore, it provided the possibility to study the effectiveness of the proposed educational activities in the context of teacher training and to investigate the relationship between simulations and hands-on activities.

In the following, we describe the implementation of the experimentation and the laboratory activities in detail.

The research questions we will address are:

- If both simulations and hands-on activities are used, does their order affect the performance?
- Do both simulations and hands-on activities present the same level of difficulty and challenge for the pre-service teachers?
- What is the pre-service teachers' view on the use of simulations compared to hands-on activities?

2 Context

The laboratory presented in this study was implemented within a course on physics education for pre-service secondary school physics teachers (*Tirocinio formativo attivo classe A049*). The general course content included a reflection on some of the difficulties that secondary school students meet when learning fundamental physics concepts and the importance of introducing scientific theory together with practical applications. Course lectures presented examples of practical work in mechanics, optics and electromagnetism.

There were 45 pre-service teachers that participated in the laboratory, 32 with a degree in mathematics, 8 with a degree in physics, 3 with a degree in astronomy, 1 engineer and 1 that did not provide information on his degree.

The laboratory was prepared by the three authors of this work, one of whom was the teacher of the course who had also taught all previous lectures.

3 Methods and Implementation

3.1 Pre-test

Before the laboratory session, several pieces of information were gathered from the participants using questionnaires.

One questionnaire assessed the participant's prior experience with hands-on laboratories and simulations. While all pre-service teachers had participated in scientific laboratory classes during their previous education at school or university, only one had been exposed to simulations in science education.

A second questionnaire served to test the participant's prior knowledge on electricity.

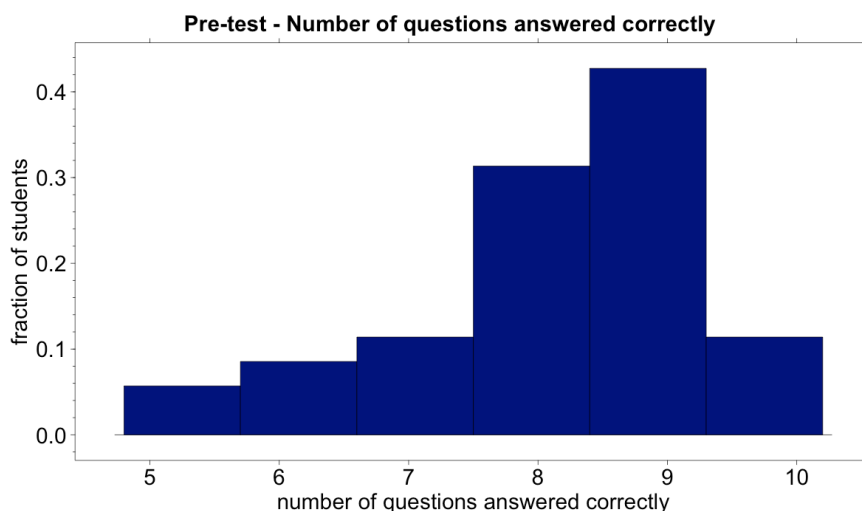


Fig. 2. Number of correctly answered questions out of a total of 10 questions in the pre-test.

The ten multiple choice questions ranged from technical questions (Q2, Q7 – Q9) to questions related to real-life application (Q1, Q3 – Q6, Q10).

Examples of the first kind of questions are:

- Q2: *What is the difference between AC and DC circuits?*
Possible answers: (a) DC is carried by electrons; AC by protons, (b) DC is carried by protons; AC by electrons, (c) DC is the flow of positive charge; AC the flow of negative charge, (d) DC is produced by electric fields; AC by magnetic fields, (e) DC does not change direction; AC does
- Q8: *The figure (see fig. 1) shows two circuits. All the resistors have the same resistance. Are the circuits equivalent?*
Possible answers: (a) Yes, (b) No

Examples of questions related to real-life application are:

- Q1: *When an electric hand mixer is used, what physical quantity is consumed (removed from the circuit and converted to another form)?*
Possible answers: (a) charge, (b) voltage, (c) current, (d) energy, (e) mass
- Q5: *The power drawn by a light bulb is controlled by the thickness of the wire forming the filament, since different thickness wires have different resistances. Consider a 100 W and a 60 W bulb. Which bulb has the thicker filament?*
Possible answers: (a) the 60 W bulb, (b) the 100 W bulb

The initial test questions may look too simple for physics and mathematics graduates, but in this experience we wanted to simulate a secondary school test that prospective teachers could use for their future students at the end of a series of introductory lectures on electricity.

The results of the pre-test on electricity are shown in figs. 2 and 3.

The overall test results depicted in fig. 2 show that the level of knowledge of the pre-service teachers was good. The mean number of correctly answered questions was 8.2 and only 13% of the participants gave less than 7 correct answers.

The results of the single questions, shown in fig. 3, reveal the main difficulties of the participants. The questions that resulted in the smallest number of correct answers (i.e. the four questions that could be answered correctly by less than 70% of the students) were Q1, Q4, Q5, and Q10, all four of which related to real-life scenarios.

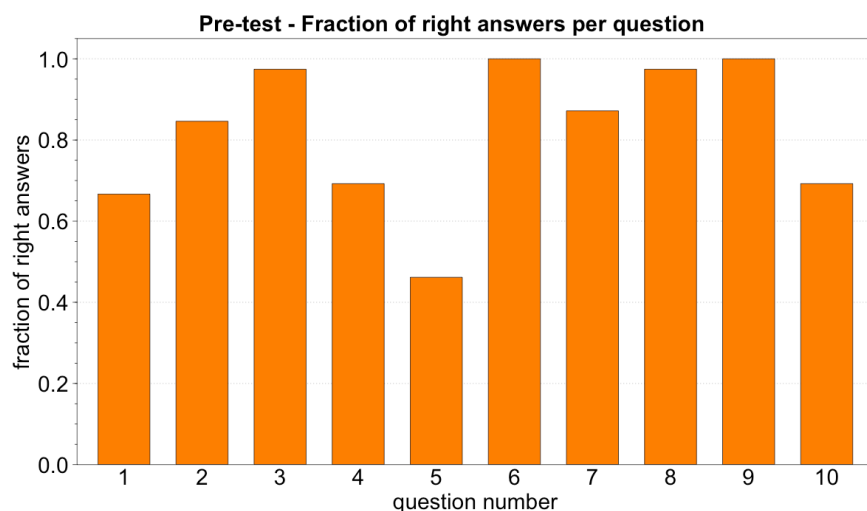


Fig. 3. Fraction of right answers for each of the 10 pre-test questions.

3.2 Laboratory Activities

In order to focus on the main difficulty the students revealed in the pre-test -that is, the application of their prior knowledge to real-life problems- the laboratory activities focused on DC circuits built with simple wires, batteries and bulbs, as can be seen in fig. 4.

The 45 participants were divided into two groups: 26 started with hands-on exercises and subsequently performed simulations, the other 19 followed the reversed order.

All simulations were performed with the PhET - Circuit construction Kit (University of Colorado, 2015). For each part, the students were given an equal amount of time of approximately two hours.

The tasks, both simulations and hands-on activities, were carried out in sub-groups of 2-3 people. They involved the construction of simple parallel and series circuits as well as real-life examples, such as the construction of a model of a chandelier with at least two bulbs and the model of a multiple electrical socket with two lamps connected.

For each constructed circuit, students were asked to determine the values of several parameters, such as the voltage and current at certain positions in the circuit and the resistance of the components, measured by a multimeter. These measurements were performed both in the hands-on activities as well as in the simulations.

3.3 Post-test

During the laboratory sessions -both simulations and hands-on activities- each participant was prompted to fill out a questionnaire that served as the post-test for this study.

Even though the students worked together in pairs or small groups, they were asked to fill out the questionnaire individually to the best of their knowledge.

Each task was structured in the following way:

1. Task instructions: what type of circuit has to be built/simulated.
2. Schematic drawing of the circuit.
3. Prediction of expected results (what happens with the bulbs when the circuit is closed, what currents and voltages will be measured at different positions in the circuit, etc.).
4. Construction/simulation of the circuit.
5. Measurement of currents and voltages with a multimeter and comparison with predictions.

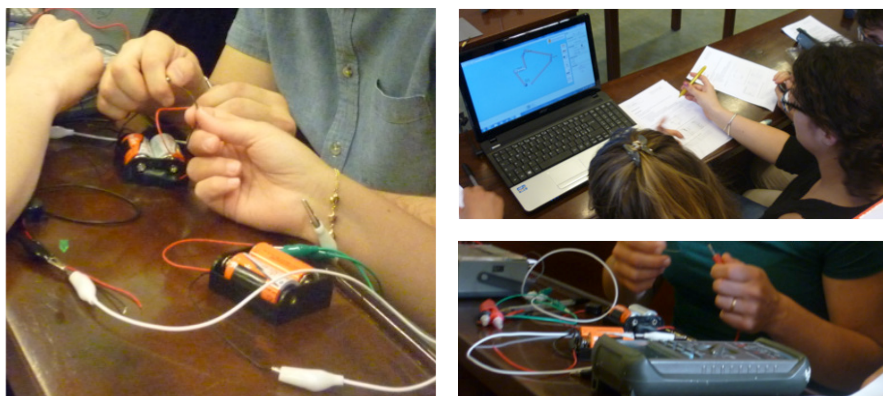


Fig. 4. Hands-on activities (left and lower right) as well as simulations (upper right).

6. Observations: which difficulties were encountered, which knowledge and abilities were acquired and/or deepened, whether any unexpected or surprising results were observed.

At the end of both laboratory units, all participants were invited to compare and evaluate the two learning environments based on their experiences. They were asked to express their opinion on both approaches, to explain if they would have preferred one of the approaches or the other, and why, and what their preferred order of the two sessions would have been.

4 Results and discussion

4.1 Timely order and performance

Significant differences were observed between the results of the tasks performed with simulations and those worked on in a hands-on approach. Even though all but one participant had no prior experience with the use of simulations in the context of science education, all pre-service teachers became familiar with the software within a few minutes and no one encountered significant difficulties during its execution. When using simulations, making correct predictions for voltages, currents, and resistances in the circuits based on prior knowledge did not present any difficulty for either of the participant groups. This confirms that simulations reinforce students' understanding of relationships between variables by providing exact agreement with the predicted outcome (Sethi, 2005).

While the pre-service teachers worked rather autonomously when performing simulations, during the hands-on activities they were continuously asking for help and the tasks created a significant challenge for them. This was despite the fact that the tasks were analogous to those carried out in the simulation session. Making predictions proved rather problematic for almost all participants, even though in principle these were equivalent to those in the simulation session, where they created no problem. The same was the case for the measurements with a multimeter, a task the pre-service teachers carried out without significant problems in the simulations.

When comparing the post-tests of the two groups, the results of the corresponding sessions, i.e. simulation or hands-on activities, respectively, are comparable. In the simulations session, the majority of all pre-service teachers succeeded in answering all four tasks, independent of the group.

This was not the case for the session employing hands-on activities. Table 1 summarizes the results of the corresponding part of the post-tests for both the group that started the laboratory with the hands-on activities and the group that had already carried out the

Hands-on task	Hands-on before simulation	Hands-on after simulation
1	25	15
2	13	5
3	4	0
4	0	0

Tab. 4. Number of pre-service teachers that completed tasks 1, 2, 3, and 4, respectively, of the hands-on session. The second column refers to the group that performed first the hands-on activities and then simulations, the third column refers to the group that had already carried out the simulations before working on the hands-on activities. 1 student of the first group and 4 students of the second group did not fill out the hands-on task section of the post-test.

simulations before working on the hands-on activities. Note that one participant of the first group and four participants of the second group did not fill out the hands-on post-test, so no information on their performance is available. No significant differences in the results of the two groups can be seen. Carrying out the tasks with the simulations first did not ease the difficulties encountered in the hands-on activities and did not have any significant effect on the performance of the pre-service teachers when answering the post-test questions.

4.2 Pre-service teachers’ view

When asked about their view on the two approaches, most pre-service teachers stated that the simulations were rather easy, intuitive, and very similar to standard exercises carried out with pen and paper. One participant’s comment summarizes this idea very well: *“The simulator does the same calculations that I do, so it is easy to predict the results”*.

The simulations were seen as a good way to repeat the basic concepts of the subject, but did not provide much opportunity to gain additional knowledge, according to the participants. The hands-on activities, on the other hand, were regarded as more stimulating and interesting than the simulations, despite the fact that the participants agreed that the level of difficulty was much higher in this case. A view that emerged frequently among the answers was that the practical applications did not correspond to theory: *“The formulas are not correct”* or *“Physics is not exact”* are two examples of statements given by the participants. This shows that the pre-service teachers erroneously expect practical applications to be a precise realization of the formulas and that they view physics as an abstract world of theories and formulas, which do not correspond to real life. This idea was supported by the results of the simulations, as these are direct visualizations of concepts. In this sense the simulations served as a good way to review theory. In order to build a bridge between concepts and real applications, however, the more advanced version of the simulations that exhibits real-life behavior and realistic instruments affected by measurement uncertainties are an essential requirement.

Independent of the fact that performance seemed unaffected by the order in which the laboratory sessions were carried out, most pre-service teachers stated that working with simulations before tackling the hands-on tasks was the preferable order. The following statement of one of the participants summarizes the opinion shared by most participants: *“Thinking of the students, I am convinced that it is more useful to let them carry out simulations first to deepen the fundamental concepts”*.

5 Summary and future work

The above findings suggest that in this experiment the sequence of the two laboratory sessions did not play a decisive role. The simulations seemed to be a straightforward application of the prior knowledge of the pre-service teachers where they were able to solve the tasks in this session without significant problems. These simulations, however, did not

help the pre-service teachers in transferring their conceptual knowledge to applications in the hands-on session. The hands-on activities provided a much larger challenge to the pre-service teachers than the simulations.

Nevertheless, most pre-service teachers stated that they found the hands-on activities more stimulating than the simulations. In their view, the simulations were a good opportunity to review theoretical contexts, in a similar manner to standard pen-and-paper exercises, but did not provide much opportunity to gain knowledge. The hands-on activities, on the other hand, offered interesting and new challenges, such as measurement uncertainties, and confronted them with the necessity of dealing with physics concepts in a new and less abstract way.

The laboratory tasks and level of complexity were designed in such a way as to demonstrate to the pre-service teachers an example of activities they can directly export to the classroom without needing adaptation. Working with simulations and hands-on materials in two distinct sessions offered the pre-service teachers a close view on both approaches, allowing them to experience the benefits and limitations of both approaches. Moreover, it provided the participants with important input for their future work in the classroom. However, from the pre-test and simulation post-test results it is clear that all participants already had thorough knowledge of the concepts of electricity, unlike secondary school students who are tackling the subject for the first time. In the case of secondary school students the order of the sessions might be important.

In order to further study the interplay between simulations and hands-on activities we will implement the laboratory sessions described above in an introductory physics laboratory course. The course will be tested with mathematics students with more limited knowledge of the subject compared to the pre-service teachers of the above experiment. A trial will also be carried out with a class of secondary students encountering the subject for the first time.

We also foresee an alternative version of the laboratory in which the simulations and hands-on activities are carried out in parallel for each task instead of separating them into two distinct sessions. In this way, we expect that the simulations will help in verifying the concepts experienced in real life and facilitate reflection on measurement uncertainties and real-life phenomena.

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Interactive Whiteboards as a Means of Supporting Students' Physical Engagement and Collaborative Inquiry in Physics

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Interactive whiteboards (IWBs) have become commonplace in classrooms in the western world. However, using IWBs productively in ways that leverage their unique possibilities for student engagement is more challenging. I propose a theoretical perspective that recognizes the IWB-based learning environment as a case of a mixed-reality (a combination of real and virtual worlds). I show how the ideas of embodied cognition and distributed cognition were used to guide the design of a learning sequence on the topic of the orbital motion of planets and I analyse its implementation. I also analyse a short video excerpt that illustrates the way in which embodiment enters high-school student discourse in the context of small-group collaborative inquiry, supported by the IWB. Students' gestures that draw on their physical experience within the IWB-based environment can help students fluently communicate ideas that would be much more difficult to express verbally.

1 Introduction

In recent decades, significant effort has been made to bring more computer-based technologies into classrooms all over the world. One example of such an effort is the introduction of interactive whiteboards (IWBs) into many classrooms in primary and secondary schools in the western world (Hennessy & London, 2013). The rationale behind disseminating IWBs —a relatively expensive project— seems to be that the new technology will allow schools to keep up with the technological advances in our everyday lives and better prepare students to function in the fast changing world of the 21st century.

However, a recent OECD report on the use of computers in schools (OECD, 2015) reaffirms what may seem obvious to educational researchers: It is not technology itself that impacts learning. Rather, it is the way we use technology that matters. It is unrealistic to expect that the mere introduction of a new piece of technology will somehow improve learning.

Research shows that teachers may not necessarily make use of IWBs at all (Somyürek, Atasoy, & Özdemir, 2009). Some teachers have managed to “absorb” the IWB into their existing practices (Warwick & Kershner, 2008), but that can hardly be considered the kind of educational revolution that some may have anticipated. Recommendations for the effective use of IWB in instruction focus on sustained teacher training in student-centred, discipline-based pedagogical practices, rather than just demonstrations of the technical capabilities of IWBs (Hennessy & London, 2013).

However, as the IWBs have not appeared as a direct response to a particular pedagogical need, it may be a challenge to justify their use in everyday instruction. It may be that the IWBs allow primary-school teachers to engage students in graphically rich and interactive activities, but are there useful ways of using the IWB in high school or university physics instruction? My experience suggests that high-school physics teachers struggle to see sig-

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nificant opportunities for the use of IWBs in novel and student-centred activities that could not be performed without the use of an IWB.

In this paper I introduce a theory-grounded approach to the design of instructional materials. The goal is to propose ways of leveraging the capabilities of the IWB's that are not available in standard computer-projector setups to support a kinaesthetically engaging and socially interactive learning environment in physics.

In section 5 of the paper I present an illustrative excerpt from a learning activity on the orbital motion of planets. I demonstrate how the IWB supported the emergence of science-like discourse among students by serving as a catalyst for students' layering (Goodwin, 2013) of different communication modalities. I pay specific attention to students' physical interaction with their virtual surroundings and their use of hand gestures to communicate and elaborate on the patterns of orbital motion. I relate my findings to previous research on the role of students' actions and gestures in the development of scientific discourse in hands-on learning environments (Roth & Lawless, 2002; Roth & Welzel, 2001; Roth, 2002).

2 Embodied and distributed cognition in mixed-reality learning environments

People make sense of new experiences by relating them to previous ones. Making sense of abstract ideas includes (often subconsciously) mapping them onto familiar mental imagery, which is, according to the principles of embodied cognition, deeply rooted in our everyday embodied sensory and motor experiences (Lakoff, 2012; Wilson, 2002).

As such, learning physics (and classical mechanics in particular) should take advantage of the way our brain works. It should help students relate their embodied experience to the physics concepts that are the objects of education. Often, this is not an easy task, especially in topics such as astronomy where our day-to-day lives do not provide us with tangible, human-scale experience.

However, the emergence of computer-based learning environments has given educators in physics and other fields new ways of approaching a diverse range of topics. Simulations, for example, allow students to observe and even manipulate virtual environments in ways that were unavailable to previous generations. As human-computer interfaces evolve, we enter an era in which those interfaces themselves are becoming more and more transparent, allowing for ever more intuitive interactions of the user with the computer. The transition from a keyboard-input terminal to touch-screens nicely exemplifies this process. New interfaces are better accounting for our physiology (Kinect, for example), making the virtual experience ever more physical and embodied.

Environments that have a virtual as well as a real-world component are often referred to as mixed reality (MR) (Lindgren & Johnson-Glenberg, 2013; Milgram & Kishino, 1994). MR environments span a continuum of experiences between the real and virtual world. These include environments that project computer graphics onto real objects, enhance virtual experiences with robot-aided haptic feedback, or, on the other end of the continuum, simply provide learners with a computer screen environment with minimal possibilities for meaningful physical input —using a computer mouse, for example. Where the use of IWBs as large touch-screens lie on this continuum depends on the way that the learner interacts with the screen and the degree to which the physical movements that he or she makes relate to the learning goals.

Lindgren & Johnson-Glenberg (2013) suggest that MR environments can have a positive impact on learning if they are appropriately fused with the principles of embodied learning. They suggest that the design of useful MR learning environments should, among other things:

Assume that embodied learning has potential benefits for all learners; take advantage of congruencies between the learner's embodied engagement and the concepts the learning is targeting; carefully select appropriate ways of conveying information by making available those aspects that are otherwise difficult to access; and provide opportunities for learners' collaboration in the learning environment.

In addition to the well-established notions of how social interactions in the learning environment can benefit learners (Johnson & Johnson, 1999; Lindgren & Johnson-Glenberg, 2013), there is another aspect to the social interactivity of MR that is tightly coupled to embodied cognition and associated learning. Embodied cognition already considers cognition as being distributed between the brain and the body. Distributed cognition goes further and considers the cognitive processes spanning individuals, their physical surroundings (Hutchins, 1995), and communities of other people (Engeström, 1987).

In the process of negotiating meaning in a group setting, students communicate by means of verbal, graphical and gestural communicational modalities, as well as actions in the MR learning environment. Gestures and actions, produced in such environments by students to communicate their ideas, are grounded in their embodied experiences from both everyday life as well as the MR learning environment itself. At the same time, the production of gestures and actions reinforces the embodied character of the learning environment. For example, the embodied experiences serve as grounding for gestures that students use in discussion, while at the same time, the enacted gestures themselves shape the cognitive processes that constitute collaborative meaning-making. The embodied and socially distributed aspects of collaborative learning in MR environments can therefore fuel each other. A collaborative and communication-rich environment can thus give rise to embodied experiences that can also benefit learning through the embodied learning route.

Previous research on social interactions has pointed to an intricate emergent system of different communication modalities in different circumstances, including learning environments (Goodwin, 2013). The embodied semiotic modes, such as physical engagement with the surroundings, as well as gestures, will be of particular interest to us in this paper, since they bring together the social and embodied aspects of human cognition.

Goodwin (2007) discusses gestures that are coupled with the physical environment and terms them *environmentally coupled gestures*. This refers to gestures that make full sense only when considered within the physical surroundings in which they are produced. Such gestures are particularly interesting in the context of IWB-supported learning, since they present a visual and an embodied link between the physical and the virtual parts of the environment.

The other such link between the real and the virtual part of the IWB-based learning environment is the manipulation of the IWB content by students' hands. I refer to this as 'action'. Action itself can also be employed as a way of conveying ideas, and can serve as a semiotic resource. Both action and gesture lie on a continuum of increasingly abstract semiotic modes, where action, being the most concrete, is followed by gesture, which is followed by language. Roth, Lawless and Welzel suggest that in the context of hands-on learning activities, students' verbal communication arises from their physical engagement with the surroundings and that scientific discourse can "piggyback" on gestures until learners develop scientific language (Roth & Lawless, 2002; Roth & Welzel, 2001; Roth, 2002). They suggest, in accordance with the above-discussed ideas of embodied learning, that optimal instruction should capitalize on students' existing capabilities of mind and body to help them learn to engage in scientific discourse. Their conceptualization of the emergence and development of scientific language is also useful in gaining a better understanding of student interactions in the IWB-based learning activities described in this paper.

3 The designed instructional materials

The two main goals of the designed materials that I refer to in this article are for students: a) to engage in science-like inquiry and discourse; b) to investigate and notice qualitatively the patterns of orbital motion, including Kepler's laws.

The design of the learning activities, collection of video data and its initial analysis were done as a part of my PhD project together with my advisors prof. dr. Gorazd Planinšič from the University of Ljubljana and prof. dr. Eugenia Etkina from Rutgers University.

For this activity, we combined the IWB with Algodoo software (www.algodoo.com)

(Gregorcic, 2015). Algodoo is a powerful and user-friendly 2-D physics sandbox software that enables users to create virtual objects in a virtual environment, tweak their properties, and study their interactions (Bodin, 2009; Gregorcic & Bodin, in press). For example, the user can create objects with a free-hand drawing, change their mass, restitution and size, and even tweak gravitational interactions and air resistance.

The activity designs were based on the principles of embodied and collaborative learning described above. The entry point for embodiment was the possibility of creating and “throwing” objects (planets) into orbit on the IWB. The movement in which students engage when throwing objects satisfies the congruency principle highlighted by Lindgren & Johnson-Glenberg (2013). The way students move their hand during the act of throwing an object on the IWB corresponds to the movement of the dragged object before its release. The object’s velocity, together with the position of the object at the moment of release, comprise the initial conditions that determine the physics of orbital motion in a two-body system. Because of this, actively throwing objects enables students to embody and vary the initial conditions of a two-body problem. It allows them to experience and enact the relevant input with their bodies. As already mentioned above, social interactions (gestures, most notably) are another route through which embodiment enters this learning environment.

Placing students into groups of three and providing them with a shared space that was accessible to all participants to see and interact with allowed for an emergence of a socially interactive environment, while maintaining an open-ended common task.

4 The setting of the study

Thus far, we have studied 3 groups of high-school students, ages 15 and 16, each engaging with the IWB and Algodoo software to study the orbital motion of planets. Students were presented with a virtual scene with a central circular object which they were told was very massive. This way, the activity continued to build on their regular physics lessons, where they had just learned about Newton’s law of gravity. The students were also familiar with the basic functions and possibilities of Algodoo software. They were given a short presentation of the software, without reference to orbital motion, a week before the orbital motion activity. The students knew they could create and drag around objects on the IWB, zoom in and out and pan around scenes.

At the start of the session, students were given short instructions. They were told to investigate how smaller objects behave in the vicinity of the more massive object that was already there. The relatively open ended initial instruction gave students freedom to explore the aspects that sparked their interest spontaneously.

In a separate paper, we reported on the roles the participants and the researcher assumed as the activity in two of the studied groups evolved (Gregorcic, Etkina, & Planinsic, 2014). The researcher also happened to be the instructor in this case, and we also considered the related social dynamics. In summary, the students were well equipped to actively engage with the IWB and Algodoo and spontaneously proposed questions and ideas for multiple representations. These included attaching tracers to objects to study the shapes of orbits and displaying velocity vector arrows to monitor their speed. These ideas could quickly be implemented in Algodoo by use of its standard functionality. The instructor (who was sitting at the back of the classroom and did not interact with the IWB) helped students manage the technical aspects of the software and occasionally steered the activity with questions and requests for clarification and elaboration.

5 Illustrative examples of embodiment through action and gesture

In the following section, I will present selected examples of student engagement with the IWB and accompanying discourse to illustrate the ways in which embodiment enters the IWB-based learning activity on orbital motion. The analysis will focus on aspects discussed above, namely: how students use actions and gestures to investigate, conceptualize, and

communicate in an IWB-based learning environment.

The following sequence of 3 environmentally coupled gestures (figures 1-3) serve as an illustration of the way science discourse “piggybacks” (Roth, 2002) on gestures. In the sequence, a student elaborates on his hypothesis that the shape of the orbit depends on the initial velocity of the object—that is, the way it is initially thrown. Even though the sequence is relatively short, it can serve as a very rich example of how gestures enter and aid communication where students are still developing the vocabulary to describe their ideas about orbital motion.

The student used the presented environmentally coupled gestures to express nuances that are more difficult to express with spoken language. The global nature of gestures (McNeill, 2008) allowed the student to express, in our case, the direction and size of the initial velocity of the object in the first gesture (fig. 1), and the orientation, eccentricity and size of the predicted orbit in the last gesture (fig. 3).

In fig. 1-3 the student explains to other participants how a new and faster throw will impact the object's orbit. He is comparing his prediction to the object's current orbit (the nearly circular orbit shape that is drawn by a tracer attached to the orbiting object – behind the student in figures 1-3).

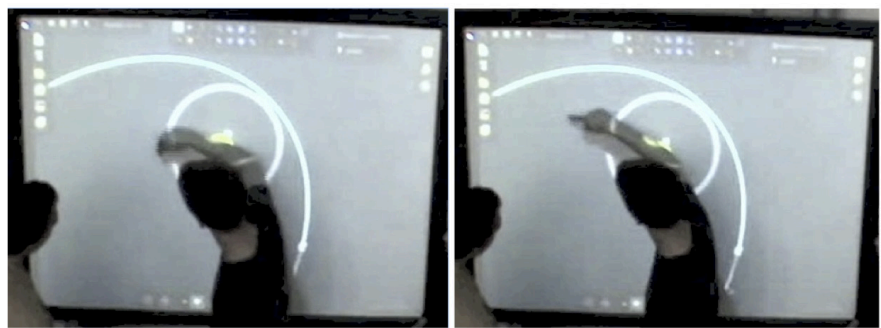
The first gesture (fig. 1) represents an “IWB throw”. It conveys the direction and speed of the proposed initial velocity of the object, as well as the throw's spatial location (the throw site). In speech, he accompanies the gesture with two deictic terms corresponding to location (“from here”), and the throw's speed and direction (“like this”).

The first gesture (fig. 1) reflects the student's previous action on the IWB – it draws on and mirrors the embodied experience of touch-screen throwing. This suggests that student gestures may emerge not only from embodied experiences they have obtained prior to the activity on the IWB (such as the everyday experience of throwing a physical object), but also from the embodied experiences in the activity itself. In our case, the touch-screen throwing gesture can serve as an indication that students' experiences in the IWB-based environment (and possibly also previous experience interacting with touch-screen applications) can become a part of the students' embodied imagery and become available for students to use in communication and collaborative sense-making.

For the second gesture (fig. 2) the student switches hands, as he simulates the initial movement of an object supposedly thrown with too much speed. Such an object “flies away” in an almost straight line (students experienced this on multiple occasions while interacting with the IWB during this activity). This can also be seen as a case of extreme-case reasoning (Zietsman & Clement, 1997). The gesture itself, with its fast stroke, communicates more than the accompanying spoken utterance. It implies a “way” of flying away, embodied through gesture. It is also indicative of a student fine-tuning his argument about what an “appropriate” throw should be like.

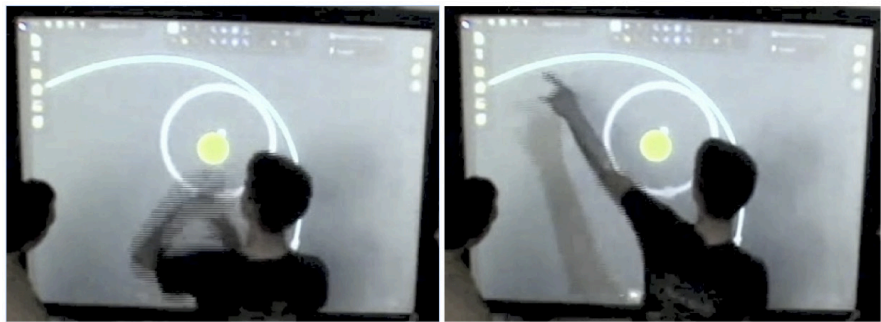
In the last snippet (fig. 3), the student predicts what a new orbit that follows the suggested throw (fig. 1), should look like, based on his hypothesis (which is, itself, based on previous experience with observing and throwing objects into orbit). Once again, the environmentally coupled gesture tells us much more than the words uttered alongside it.

The gesture in fig. 3 expresses the approximate eccentricity and orientation of the proposed orbit, while the coupling with the underlying environment also indicates the orbit's position relative to the Sun. The “back in” in the student's words, is in agreement with the gesture, since it suggests a changing distance between the object and the Sun and may also suggest (combined with the gesture stroke which ends roughly at the point where the trajectory started) that the student has noticed the closed nature of orbits (the object follows its own path repeatedly). Any of the above noted attributes of the gesture can be recognized as indications of the student's emerging understanding of the way objects orbit a massive central object, such as the Sun. Thus, allowing students to physically engage and express their ideas in the IWB-based environment can empower them to better express what they notice and how they think.



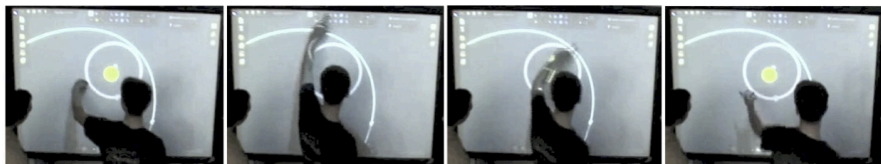
If we throw it from here like this...

Fig. 1. The student explains to other participants how they should throw an object on the IWB in order to observe a new trajectory of motion (a new orbit). He uses an environmentally coupled gesture, with which he communicates how (direction and speed) and where (the spatial position of the throw) they should perform the throw.



... but no too much, so that it doesn't fly away...

Fig. 2. In the second gesture, the student fine-tunes his argument about how they should throw the object. His gesture, somewhat different from the previous throwing gesture (no contact with the board, no indication of a "dragging" motion with his finger), embodies an image of an object being thrown very fast, so that it "flies away" in an almost straight line.



...then I think it would go back in on an ellipse.

Fig. 3. The student enacts the shape of the predicted orbit of an object around the Sun. In the environmentally coupled gesture we can see a number of physically relevant attributes, which in fact depend on the initial velocity of the object. These include the ellipse orientation, eccentricity and positioning relative to the Sun.

6 Discussion

As we have seen in the example presented in this paper, observing student gestures allows us, the researchers, to obtain better insight into student thought (Scherr, 2008). These observations also allow us as developers of instructional materials to recognize in what ways the learning environment at hand is contributing to students' embodied imagery. Furthermore, such observations indicate what previous imagery students are bringing into and drawing on in mixed-reality investigative learning activities. In the example presented in the previous section, we saw the student drawing on his experiences from the activity itself (the throwing gesture, the movement of an object thrown "too fast"). However, student's previous experiences with touch-screen technology may have played a substantial role as well. One of the suggestions for future research would be to explore in what ways interactions with touch-screen devices shape the learners' embodied imagery and how they use such imagery in new circumstances.

Our learning materials take seriously the need for content-embodiment congruency in mixed reality learning environments (Lindgren & Johnson-Glenberg, 2013). This means that students' physical engagement with the environment is closely related to the relevant physics concepts that the learning environment aims to address. We have seen that in our case, the embodied resources (actions and gestures) related to orbital motion have also been productively used in student communication. Through environmentally coupled gestures, students were able to express relatively complex ideas. This enabled fluent discourse among the participants in the small-group activities that were studied. These gestures allowed students to engage in scientific discourse before they mastered the formal terminology associated with the topic at hand. I hope that research in the future will look further into how mixed-reality learning environments can contribute to education by leveraging the processes of embodied learning.

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Non-Users, Lurkers, and Posters in the Online AP Teacher Community: Comparing Characteristics Determining Online Engagement

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This empirical study explored participation patterns of 1,733 Advanced Placement (AP) Physics teachers in the online AP teacher community (APTC) following the redesigned AP science examinations in the United States. We identified profiles of teachers with different levels of engagement in this peer-based online learning community. Our results provide insight into underrepresented user groups and the development of more personalized online teacher support systems. Our analysis suggested that teachers' knowledge and experience, the enactment of AP practices, challenges with the AP redesign, and AP workload were all significantly associated with changes in the probability of teachers becoming APTC users. This indicated that the APTC attracted a non-representative population sample of all AP physics teachers. However, most teacher, teaching, and school characteristics provided no indication as to whether APTC users were posters or lurkers.

1 Introduction

This study analyzed teacher engagement patterns in a peer-based online learning community. It is part of a longitudinal National Science Foundation funded research project on teacher learning related to the redesign of the Advanced Placement (AP) examinations in the United States. AP courses provide rigorous, college-level learning opportunities for high school students on a broad range of subjects. The summative AP examinations (graded on a 1-5 scale) are high-stakes because students might be able to substitute introductory college courses with passing grades above a threshold value in AP courses (usually 3 or higher), depending on corresponding college policies. In addition, AP courses increase students' competitiveness in the U.S. college application process.

In response to recommendations from the National Research Council (2002), the College Board (the provider of the AP examinations) increased the emphasis on scientific inquiry, reasoning, and depth of conceptual understanding while de-emphasizing rote memorization and algorithmic schemata. This nation-wide redesign in the sciences was introduced in 2013 (Biology), 2014 (Chemistry), and 2015 (Physics). Preparing teachers for these large-scale changes, the College Board and other providers offered a broad range of professional development (PD) opportunities, including face-to-face workshops, self-paced online courses, downloadable materials, and peer-based online learning communities. Prior analysis indicated that, while some characteristics of teachers and schools were linked with student scores, significant direct associations for most PDs on student performance were difficult to confirm (Fischer et al., 2015; Fishman et al., 2014). However, out of the PD options studied, participation in the online AP teacher community (APTC)

Fischer, C., Frumin, K., Dede, C., Fishman, B., Eisenkraft, A., Jia, Y., Kook, J. F., Levy, A. J., Lawrenz, F., & McCoy, A. (2016). Non-Users, Lurkers, and Posters in the Online AP Teacher Community: Comparing Characteristics Determining Online Engagement. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 109–117). Mulhouse: European Physical Society.

had the most consistent, direct, and positive association with both teaching practices and students' AP scores (Fishman et al., 2014). To better understand this, we chose to further study teachers' APTC participation and engagement patterns. Our findings might also benefit teachers faced with other large-scale curriculum changes, such as the Common Core State Standards Initiative or the Next Generation Science Standards.

2 Theoretical Framework

2.1 Peer-Based Online Learning Communities

Successful peer-based online learning communities can be seen as "*communities of practice*" (Lave & Wenger, 1991) in a virtual environment "*where people come together with others to converse, exchange information or other resources, learn, play, or just be with each other*" (Kraut & Resnick, 2012, p. 1). Barab, MaKinster, and Scheckler (2003) define such virtual communities of practice as "*persistent, sustained social network[s] of individuals who share and develop an overlapping knowledge base, set of beliefs, values, history and experiences focused on a common practice and/or mutual enterprise*" (p. 238).

To distinguish participation patterns in online communities, users are often categorized as either posters or lurkers. *Posters* describe users who generate visible content, whereas *lurkers* are depicted as silent, observation-oriented, and 'invisible' users. Although lurkers' engagement is commonly viewed as passive, lurkers are valuable participants in, for instance, providing an audience for posters, or engaging in goal-driven, active information seeking behavior (Edelmann, 2013). Thus, based on the context, lurking might be characterized as "*legitimated peripheral participation*" (Lave & Wenger, 1991) in virtual communities of practice.

2.2 Professional Development Participation

In the complex system of schooling, the importance of teachers in improving student learning outcomes is widely acknowledged (Hattie, 2009). Teacher education and PD programs are seen as crucial for raising student achievement in educational reform efforts (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Loucks-Horsley & Matsumoto, 1999). Models of teacher learning emphasize the mediating character of PD programs. High-quality PD seeks to increase teachers' knowledge and skills, which in turn lead to changes in instructional practices, ultimately fostering student learning and achievement (Desimone, 2009; Fishman, Marx, Best, & Tal, 2003). Systematic empirical research efforts on PD effectiveness identified several design characteristics constituting 'high-quality' PD (e.g., Banilower, Heck, & Weiss, 2007; Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007), which Desimone (2009) summarizes as (a) content focus, (b) active learning, (c) coherence, (d) duration, and (e) collective participation.

While the majority of empirical studies analyzed these PD characteristics for traditional face-to-face PD activities, Dede, Ketelhut, Whitehouse, Breit, and McCloskey (2008) described the current state of research on online teacher PD activities. Fishman et al. (2013) provided an overview of the relatively few studies comparing face-to-face and online PD programs. However, the research base on online teacher communities is still developing.

2.3 Research Questions

This study represents an effort to extend the research base on online teacher community research by exploring characteristics that predict different types of PD engagement (non-user, lurker, and poster) in the APTC. This study explored AP Physics teachers' participation and engagement profiles in the APTC through the following research questions:

1. What patterns of teacher and school characteristics exist among non-users and users of the APTC?
2. What patterns of teacher, school, and APTC engagement characteristics exist among lurkers and posters?

This study defined *non-users* as teachers who did not participate in the APTC at all. *Users* were categorized as self-reported APTC participants (either lurker or poster). Given that the field did not establish universal definitions of lurkers and posters, we categorized teachers as lurkers and posters using three slightly different approaches based on teachers' self-reported activities within the APTC. Thus, we accounted for the sensitivity of this conceptualization by applying statistical models that only differed in the lurker-poster categorization. The following lurker-poster categorizations were applied:

1. *Lurkers* were APTC users who self-reported as never having posted in APTC online forums and never having uploaded any teaching resources. *Posters* were teachers who self-reported as having posted at least once in an online forum or uploaded at least one teaching resource.
2. *Lurkers* were APTC users who self-reported that they spent less than 2.5% of their time in the APTC posting in online forums and/or uploading teaching resources. *Posters* were teachers who self-reported that they spent at least 2.5% of their time in the APTC posting in online forums and/or uploading teaching resources.
3. *Lurkers* were APTC users who self-reported that they spent less than 5.0% of their time in the APTC posting in online forums and/or uploading teaching resources. *Posters* were teachers who self-reported that they spent at least 5.0% of their time in the APTC posting in online forums and/or uploading teaching resources.

3 Methodology

3.1 Data Sources

Web-based surveys were sent to all AP Physics teachers in May 2015 except for teachers who were placed on a 'do not contact' list; the surveys asked about demographic information, teaching background, concerns with the AP redesign, PD participation, attitudes towards PD, AP science course instruction, and school context. The response rate for the 2015 AP Physics survey was 33.65%. The sample for this study included data from AP Physics teachers ($N=1,733$) teaching in the United States. Non-parametric Mann-Whitney tests indicated that the schools of the teachers who responded to the survey were associated with slightly lower enrolment in free- or reduced-priced lunch programs ($M = 28.31$, $SD = 24.49$) compared to the schools of teachers who did not respond to the survey ($M = 31.79$, $SD = 25.18$), $z = 4.190$, $p < 0.001$, $d < 0.139$.

In order to reduce sampling biases, missing data was imputed through Markov Chain Monte Carlo multiple imputation methods with 150 iterations and 40 imputations, yielding power falloffs smaller than 1% compared to full information maximum likelihood approaches (Graham, 2009). Also, teachers responding to less than 1/3 of the survey questions were dropped from the analysis.

3.2 Measures

The dependent variable used in the first research question concerned whether teachers were *non-users* ($N = 1,003$) or *users* ($N = 730$) of the APTC. The dependent variable in the second research question indicated teachers' APTC engagement as lurkers or posters (def. 1: $N_{\text{lurk}} = 409$, $N_{\text{post}} = 321$; def. 2: $N_{\text{lurk}} = 449$, $N_{\text{post}} = 281$; def. 3: $N_{\text{lurk}} = 480$, $N_{\text{post}} = 250$).

Single indicator independent variables included demographic information such as teachers' *birth year*, *gender*, and *racial background*. Regarding APTC participation, teachers were asked to report their average *frequency* and *duration* of APTC visits. Inspired by Desimone's (2009) characteristics of 'high-quality' PD, five-point Likert scale variables were used to assess teachers' perceptions of how *responsive the APTC was towards their needs and interests*; if teachers' interactions with the APTC had a *focus on student work*; if *teaching was modeled* in teachers' interactions with the APTC; if teachers used opportunities to *build relationships with colleagues*; and if teachers felt *effectively supported with teaching the redesigned AP course*. Furthermore, teachers indicated whether *accessing re-*

sources, asking questions, obtaining recommendations regarding the AP redesign, sharing ideas and insights, and social interactions were reasons for their APTC participation. Teachers' racial background as well as frequency and duration of APTC participation were included as a series of dummy variables (but were still counted as single indicator variables).

Composite independent variables were computed based on exploratory and confirmatory factor analysis, as well as conceptual considerations. The number of retained factors was determined through the Guttman-Kaiser criterion and scree plot analysis. Parameters were derived with normalized oblimin oblique rotation methods computing standardized Bartlett factor scores. The following composite variables were included:

- *Teachers' PD inclination* (importance of PD to instructional performance, importance of PD to student performance, effectiveness of self-teaching, efficacy of PD participation, enjoyment of face-to-face PD);
- *Teachers' self-efficacy* (student performance is based my effort, students get better scores due to effective teaching, teaching overcomes inadequate students science backgrounds, extra teaching effort does not change AP scores);
- *Teachers' knowledge and experience* (years teaching high school science, years teaching AP science, professional science teaching organizations, conference attendances, years serving as AP Reader, years serving as AP Consultant, time of assignment for AP science);
- *Enactment of AP redesign practices* (students conduct lab investigations, conduct inquiry lab investigations, report lab findings to each other, use lab science practices in class, guidance on content questions, guidance on open/free response questions);
- *Enactment of the AP redesign curriculum* (refer to the "*Big Ideas*," refer to how enduring understandings relate to the "*Big Ideas*," refer to learning objectives from AP curriculum, refer to the curriculum framework);
- *Challenges with the AP redesign* (content, organization of content, labs, inquiry labs, format of questions/problems/exam, application of science practices, new syllabi, "*boundary statements*," design new student assessments, use the textbook, work with new/different textbooks, pacing of course, move students to conceptual understandings);
- *AP workload* (number of students across all AP science sections, number of AP science sections, number of preps); and
- *Administrative support* (principal understands challenges for AP students, principal understands challenges for AP teachers, principal supports PD, lighter teaching load for AP teachers, fewer out-of-class responsibilities, additional funding for AP, availability of lab equipment, availability of consumable supplies).

3.3 Analytic Methods

Exploring both research questions, logistic regression analysis was conducted on teachers' APTC participation (research question one) and teachers' engagement as lurkers or posters (research question two). Teachers' APTC engagement is further explored with a sensitivity analysis that used the different lurker/poster definitions.

The assumptions of logistic regression were met. Teachers were uniquely distributed across binary teacher groups (non-user/user; lurker/poster). The sizes of the teacher groups were sufficiently large to conduct logistic regression analysis, fulfilling Peduzzi, Concato, Kemper, Holford, and Feinstein's (1996) recommendation of more than 10 observations for every independent variable included in the analysis.

4 Findings

4.1 Participation Patterns among Non-Users and Users

The results of the logistic regression analysis indicated that certain teacher demographics, teaching, and school characteristics significantly predict whether teachers chose to participate in the APTC (table 1).

	β	Odd ratios	z
Intercept	-14.732		
<i>Teacher demographics</i>			
Birth year/100	0.724	2.063	1.30
Female	0.473***	1.606***	4.34***
Racial background (vs. White)			
Native American	-1.257*	0.284*	-2.55*
Asian or Asian American	-0.296	0.744	-1.19
Black or African American	-0.389	0.678	-1.03
Hispanic	-0.129	0.879	-0.48
Knowledge and experience ^c	0.213***	1.238***	4.19***
<i>Teaching and school characteristics</i>			
PD inclination ^c	0.020	1.020	0.38
Self-efficacy ^c	0.057	1.058	1.38
Enactment: AP practices ^c	0.222***	1.248***	4.83***
Enactment: AP curriculum ^c	0.069	1.072	1.40
Challenges with AP redesign ^c	0.227***	1.254***	4.50***
AP workload ^c	0.112*	1.119*	2.39*
Administrative support ^c	0.084	1.087	1.75

Tab. 1. Logistic regression analysis exploring the likelihood of teachers being non-users or users of the APTC (N = 1,733); ^c: Composite variable; *p<0.05, **p<0.01, ***p<0.001.

With everything else constant, the main significant findings were the following: Regarding teacher demographics, female teachers and teachers with greater knowledge and experience were significantly more likely to participate in the APTC. Female teachers' odds of APTC use were 60.6% greater than those of their male counterparts. Roughly every standard deviation increase in teachers' knowledge and experience was associated with a 23.8% increase in the odds of APTC participation. Regarding teaching and school characteristics, teachers who used more AP redesign practices in their AP course enactment, who felt more challenged by the AP redesign, or who experienced a higher AP workload were significantly more likely to participate in the APTC. Roughly every standard deviation increase in teachers' enactment of AP redesign practices was associated with a 24.8% increase in the odds of APTC participation. Roughly every standard deviation increase in the challenges with the AP redesign reported was associated with a 25.4% increase in the odds of APTC use, and roughly every standard deviation increase in teachers' AP workload was associated with a 11.9% increase in the odds of APTC use.

The influences of teacher, teaching, and school characteristics on teachers' likelihood of APTC participation can also be illustrated by calculating predicted probabilities. For instance, figure 1 suggests that the more teachers felt challenged with the AP redesign, the higher the predicted probability of participating in the APTC is, when all other variables are at their mean or mode values. Also, the gender gap in the predicted probabilities of APTC use is fairly stable across variations of teachers' perceived challenges with the AP redesign.

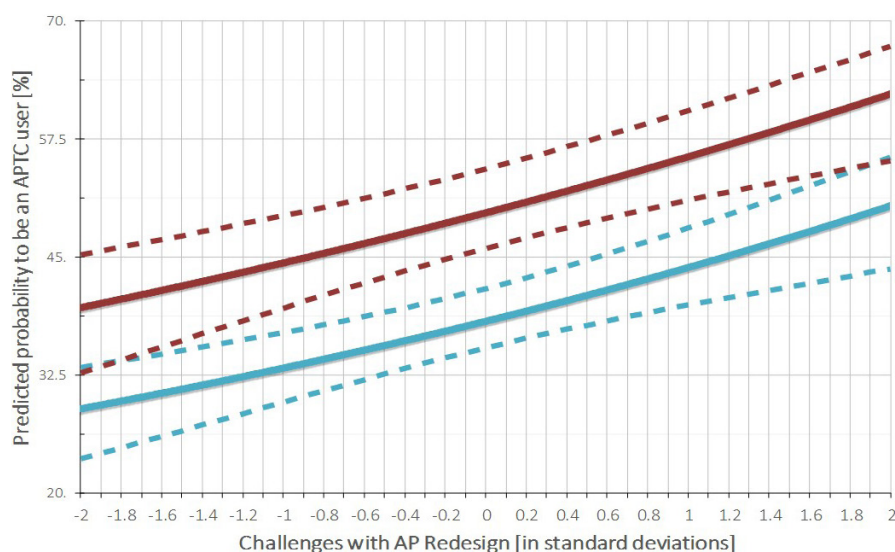


Fig. 1. Predicted probabilities of APTC participation for female (red) and male (blue) teachers with varying degrees of perceived challenges with the AP redesign; the dashed lines represent 95% confidence intervals.

4.2 Participation Patterns among Lurkers and Posters

The teacher, teaching, and school characteristics we measured and included in the logistic regression analysis did not significantly predict whether teachers were lurking or posting in the APTC, even accounting for differences in the definition of lurkers and posters through a sensitivity analysis (table 2). Significance levels for each variable were equal across all lurking and posting definitions with the exception of teachers' racial background (Black or African American vs. White) for the 2.5% threshold definition.

Nevertheless, analyzing teachers' engagement in the APTC in more detail provided insight into whether teachers were lurkers or posters. Teachers' self-reported reasons for participating in the APTC substantially distinguished lurkers from posters. AP Physics teachers who participated in the APTC to ask questions about the redesign had greater odds of being posters than lurkers (>0% threshold: 531.9%; 2.5% threshold: 541.5%; 5.0% threshold: 492.4%). Similarly, AP Physics teachers who participated in the APTC to share their ideas and insights also had greater odds of being posters than lurkers (>0% threshold: 2,210.7%; 2.5% threshold: 2,067.4%; 5.0% threshold: 1,820.6%). Remarkably, none of the 'high-quality' PD characteristics inspired by Desimone (2009) showed significantly changes in the predicted probabilities of teachers being posters or lurkers. This indicated that the perceived PD experiences regarding the 'high-quality' PD characteristics for AP Physics APTC users' might be similar for both lurkers and posters.

5 Discussion and Recommendations

This study contributes to the research base exploring teachers' participation and engagement patterns in peer-based online learning communities. Ultimately, this project aims to understand what teacher supports are correlated with student outcomes during large-scale changes in tests and curricula. The shift in the AP science curricula constitutes a unique opportunity to examine teachers' PD participation patterns, including in the College Board's APTC. Additionally, this study represents a unique opportunity for online community research because it builds upon common approaches that solely analyze populations *within* online communities. We are able to compare APTC users to *non-users*, due to our nation-wide sample of AP Physics teachers.

	[a]		[b]		[c]	
	β	Odd ratios	β	Odd ratios	β	Odd ratios
Intercept	-10.526		-7.060		-1.841	
<i>Teacher demographics</i>						
Birth year/100	0.449	1.566	0.284	1.329	0.035	1.036
Female	-0.367	0.693	-0.279	0.757	-0.320	0.726
Racial background (vs. White)						
Native American	0.050	1.052	0.423	1.526	0.679	1.973
Asian or Asian American	0.467	1.595	0.830	2.294	0.888	2.431
Black or African American	0.221	1.247	-1.934*	0.145*	-1.589	0.204
Hispanic	-0.076	0.927	0.375	1.454	-0.005	0.995
Knowledge and experience ^c	0.121	1.128	0.058	1.060	0.103	1.108
<i>Teaching and school characteristics</i>						
PD inclination ^c	-0.071	0.932	-0.156	0.855	-0.179	0.836
Self-efficacy ^c	0.053	1.055	0.097	1.101	0.109	1.115
Enactment: AP practices ^c	0.005	1.005	-0.029	0.972	-0.029	0.971
Enactment: AP curriculum ^c	-0.108	0.897	-0.029	0.972	0.009	1.009
Challenges with AP redesign ^c	0.080	1.083	0.086	1.090	-0.024	0.977
AP workload ^c	-0.014	0.986	-0.034	0.966	-0.017	0.983
Administrative support ^c	-0.031	0.970	-0.037	0.964	-0.083	0.920
<i>APTC participation characteristics</i>						
Frequency (vs. once per month or less)						
Every other week	0.167	1.182	0.030	1.031	0.074	1.077
Once or several times a week	0.319	1.375	0.293	1.341	0.304	1.355
Almost every day	0.106	1.112	-0.015	0.985	0.293	1.341
Duration (vs. less than 5 minutes)						
5 to 10 minutes	0.656	1.928	0.666	1.946	0.186	1.205
10 to 20 minutes	0.669	1.952	0.611	1.842	0.298	1.347
20 to 40 minutes	0.626	1.870	0.453	1.572	0.422	1.525
More than 40 minutes	0.219	1.245	-0.079	0.924	-0.473	0.623
PD characteristics						
Responsive agenda	-0.029	0.971	-0.018	0.983	-0.037	0.964
Focus on student work	0.129	1.137	0.175	1.191	0.188	1.207
Modeling teaching	-0.057	0.944	-0.100	0.905	-0.093	0.911
Building relationships	0.162	1.176	0.143	1.154	0.078	1.081
Effective support	-0.043	0.958	-0.077	0.926	-0.033	0.968
Reasons for participation						
Access resources	-0.112	0.894	-0.248	0.780	-0.322	0.725
Ask questions	1.844***	6.319***	1.859***	6.415***	1.779***	5.924***
Recommendations for AP redesign	-0.238	0.788	-0.511	0.600	-0.661	0.516
Share ideas/insights	3.140***	23.107***	3.076***	21.674***	2.955***	19.206***
Social interactions	-0.142	0.868	0.036	1.037	0.141	1.152

Tab. 2. Logistic regression analysis on the likelihood of teachers being lurkers or posters ($N = 730$);^c: Composite variable; posters are teachers who posted and/or uploaded teaching resources at

least [a] once, [b] 2.5% of their time spent in the APTC, [c] 5.0% of their time spent in the APTC;

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The two main findings of this study are the following: First, the APTC is used by a particular teacher population in physics. APTC participation is more likely for female teachers, more knowledgeable teachers, teachers who enacted more AP redesign practices, teachers who experienced more challenges with the AP redesign, and teachers who reported a higher AP workload. This conclusion identified a selection bias in APTC participation patterns and, as such, APTC users are not representative of the overall AP Physics teacher population who responded to our survey. The uniqueness of the APTC teacher population might be attributable to characteristics of the APTC community. The APTC provides a rich environment in which teachers share teaching resources and engage in meaningful conversations on how to successfully approach teaching redesigned AP courses. This in turn might explain the positive correlations of teachers' APTC use on students' AP scores (Fishman et al., 2014). Secondly, none of the included teacher, teaching, and school characteristics significantly predicted whether AP Physics teachers were using the APTC as lurkers or posters. This indicated that lurkers and posters shared key characteristics and that APTC participants are not distinguishable based on individual teacher and school contexts *per se*. Teachers' self-reported reasons for participating were the most predictive factors for lurking or posting behavior, which indicated that the design of the APTC allowed teachers to choose how to participate in order to reach their individual goals.

Given the findings of this study, recommendations for researchers, PD providers and developers of online communities are as follows. First, before generalizing from a sample of users in an online community to the overall population (including non-users), statistical analysis should verify representativeness of the sample of online community users compared to non-users, instead of only comparing lurkers and posters. Secondly, if the intent is to diversify the population of an online teacher community, recruiting efforts should be intensified for underrepresented teacher populations (male teachers, teachers who enact fewer curricular reform elements, less knowledgeable and experienced teachers, teachers experiencing fewer challenges with curricular reforms, and teachers with lower teaching workloads).

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GAME-BASED LEARNING IN PHYSICS

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Exploring Physics with Video Games

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We introduce our *Exploring Physics with Video Games* project, which consists of creating a cutting-edge electronic book that combines classic arcade games, new app-based games, and physics instruction in one self-contained ePub, readable (and playable!) on a computer, tablet, or smartphone. The book is for people interested in video games and in the physics behind them—the physics that makes objects move, bounce, shoot, explode, collide, and jump. Classic video games like Frogger, Missile Command and many others were all created with basic physics. Many recent games like Angry Birds, Flappy Birds, and Cut the Rope are based on a robust physics engine that performs calculations in the game. In some parts of the games, the physics is realistic. In other parts, it is “fake.” We discuss the technical features and pedagogical approach used for the eBook, as we explore new ways to deliver fun, educational eBooks. All of the games were created with Easy Java/JavaScript Simulations.

1 Pedagogical context

The average American student between thirteen and eighteen years old spends one hour and twenty minutes per day playing video, computer, or mobile games (Common Sense Media, 2015). During their 3,000 hours with an electronic game in these years, teen students learn to solve problems, determine rules, strategize, recognize patterns, and guess intuitively. They conquer worlds, learn through failure, hypothesize, and figure out the laws of a game’s universe. Jose Bowen (2012) calls video games “the ubiquitous model for understanding and delivering interactive learning”.

Game programmers design video games so that they can be learned without a textbook, homework, lectures, or exams. Video games are teachers that reach an array of learners with different abilities, preferences, and backgrounds. Furthermore, video games succeed by teaching hard, challenging skills, without the player giving up. As a result, video games seem to do the impossible—they are challenging and frustrating, yet motivating.

Gee (2007) describes thirty-six learning principles that are also qualities of successful video games. Bowen (2012) describes nine of these qualities that make video games such good teachers. They include:

- *Risk-taking*: Good games decrease the pain and consequences of failure and encourage taking risks. Lessons learned from failing can immediately be applied to new, related challenges.
- *Performance before competence*: As Bowen states, “A good game needs no instruction manual.” Students (gamers) can fully participate and achieve some success even before they are fully competent.
- *Pleasant frustration*: According to Bowen, providing students with a surmountable challenge is the “sweet spot” for engaged learning. If a game is too easy or too hard, the gamer (student) will give up. Like the story of Goldilocks, the challenge must be “just right.” A good game can even adjust the challenge to the level of the player in order to maintain this feeling of pleasant frustration.

Titus, A., & Esquembre, F. (2016). Exploring Physics with Video Games. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 121–127). Mulhouse: European Physical Society.

This leads us to our primary question. Can we use video games to teach physics? There are two major components to the question. (1) Does the goal of winning a game inspire students to learn the physics of the game? (2) Does playing a game enable students to gain insight into physical phenomena?

It is useful at this point to define the difference between a video game, a simulation, and an animation. An extensive meta-analysis on computer simulations in teaching (SRI Education, 2014) defines video games as “having clear goal states and a built-in reward system.” Simulations include interactivity where the user can “set parameters for modeling a phenomenon or system.” Visualizations (or what we call animations) are other tools that do not include this kind of interactivity. In summary, goal states and a reward system are essential for distinguishing games from simulations.

There are excellent books that illuminate physics for the purpose of building a physics engine or adding realism to games. Palmer (2005) gives a nice overview of related topics in mathematics, kinematics, and Newtonian mechanics and then provides detailed description and example programs for modelling projectile motion, collisions, explosions, rocket motion, buoyancy, driving, and flying. Millington (2010) provides both physics instruction and code for developing a physics engine for games. Ramtal and Dobre (2014) give advice for developing a physics engine in JavaScript. Our goal is different, however: we want to teach physics through games and develop technology that makes this possible.

2 The Exploring Physics with Video Games project

To help answer these questions and accomplish this goal, we are developing an electronic book (eBook) on physics with games embedded in the eBook. *Exploring Physics with Video Games* combines classic arcade games, new app-based games, and physics instruction in one self-contained eBook that is readable (and playable!) on a computer, tablet, or smartphone. Our eBook is intended for students of all ages and all levels, in both formal and informal educational settings, who are interested in video games and in the physics behind them—the physics that makes objects move, bounce, shoot, explode, collide, and jump. Classic video games like Asteroids, Space Invaders, Lunar Lander, Frogger, and Missile Command were all created with basic physics. Many recent games like Angry Birds, Flappy Birds, and Cut the Rope are based on a robust physics engine that performs calculations in the game. In some parts of the games, the physics is realistic. In other parts, the physics is “fake,” meaning the game follows laws of physics from a fictional universe or employs fictional technology in the game’s world that is not apparent to the user.

An additional technical goal of this project is to determine the state of the art for creating such eBooks from the point of view of a physics instructor who is typically not a professional programmer or computer expert. What high-level tools can be used to create the complete eBook, from its narrative to the games to putting all the pieces together in order to create the final product?

We are biased by our previous work. We have game-based physics teaching experience through the lab-based course *Physics for Video Games*, created and used by Aaron Titus as a physics course for non-science majors at High Point University. The course relies on a PDF document and VPython instruction to teach students to program simple games based on physics principles (Titus, 2012).

We are also long-time users of the Easy Java/JavaScript Simulations (EjsS) modelling and authoring tool (Esquembre, Easy Java/JavaScript Simulations web page, 2015). This is a free, open-source application created by Francisco Esquembre for writing and deploying simulations with mathematical modeling. EjsS is designed to help non-programming experts create simulations of scientific and engineering phenomena from a high-level perspective, concentrating on the domain-specific aspects of the simulation, and letting the computer automatically do all of the computer tasks that can be automated (such as numeric routines, animation, interaction and visualization capabilities). Since EjsS release 5.0, programs created using the JavaScript *flavor* of EjsS run in a browser and in an

app on computers, tablets, and smartphones. Easy Java/JavaScript Simulations is part of the Open Source Physics project (Christian, Esquembre, & Barbato, 2011). Tutorials and a collection of EjsS simulations are available on ComPADRE (ComPADRE, 2015).

Due to our previous experience and work, our high-level authoring approach, and the capability of running EjsS simulations on virtually any platform, we decided to create all of the games in JavaScript, using Easy Java/JavaScript Simulations. That was only part of the work, however. We also needed to figure out how to create a narrative in an author-friendly form and how to embed games with a narrative into an eBook.

3 Pedagogical structure and goals for the eBook

From the pedagogical point of view, our goals were straightforward. We wanted to:

- Create an attractive narrative, easy to follow for people without prior particular physics education.
- Use the games and the narrative to motivate learning physics.
- Challenge the reader, in the best gaming style, to become active in learning physics.

Pursuing these objectives, our design for the eBook is based on the following guiding principles:

1. Each chapter begins with a game that is based on a historically classic arcade game or a well-known modern-day mobile game (Kent, 2001).
2. After playing the game and trying to beat the level, the student reads the text that explains the mathematics or physics behind the game. The text elucidates the math or physics used by the “physics engine” in the game and also illustrates how to beat the game.
3. The student can play the game again in manual mode or can play it in automatic mode. In automatic gameplay, the computer plays the game automatically and the reader observes what can be achieved using the predictive capability of Newtonian physics. Typically, the automatic gameplay achieves scores that are not humanly possible.
4. For more advanced readers, the games may offer them the opportunity to program their own custom automatic gameplay strategy.
5. In some cases, historical games were unphysical. For example, the spaceship in Asteroids slows down as if there is air resistance. In these cases, we provide versions of the game with both correct physics and incorrect physics and show how adding correct physics affects gameplay. (Of course, “correct” and “incorrect” depend on our assumptions of the physical laws and environment of the game.)

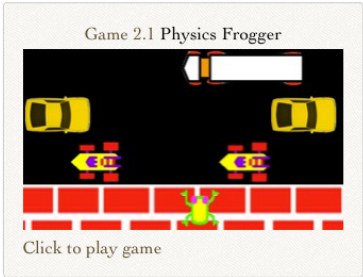
As an example, the first chapter with physics content is devoted to *Coordinates in Two Dimensions* and uses the game Physics Frogger (based on the classic Frogger game) to motivate the physics. (To distinguish our games from commercial versions of similar games, we append “Physics” to the title of the game.) Figure 1 shows a screen capture of the eBook pages where the game is presented. Clicking on the book’s image of the game, a full-screen game pops up and allows the reader to play a fully functional version of the game (Figure 2).

After playing Physics Frogger and discovering that the key to crossing the obstacles is to anticipate, well in advance, when one or more given positions are safe, the reader resumes reading. The narrative then explains the notion of coordinates as a way of specifying positions precisely, and introduces an algorithm for the frog to automatically cross the scene based on a function (provided by the game) whose return value specifies if a given (x,y) position is safe. The game can then be observed in automatic mode where it uses this algorithm. The reader can even try to beat it manually by replaying the game with certain initial settings.

To make the challenge more interesting, the notion of displacement and distance is then introduced and the user is instructed to play the game again with three additional goals: (1) Safely reach a randomly chosen final position. (2) Do this by minimizing the total distance travelled by the frog. (3) Do it in the minimum possible time. This introduces two scores (one in time, one in distance) and the user is challenged to minimize them (see Figure 3).

2.1 Game: *Physics Frogger*

Move the frog safely to a lily pad. Ideally, you should aim for the yellow one, which is selected randomly at the start of the game. The frog dies if it travels off the screen (to the left or to the right), if it is hit by a vehicle, or if it falls into the water. To get across the water, it must jump onto floating objects, including the turtles and fish.



- 1. Click or tap to begin. If the frog dies or if it safely reaches the lily pad, then click or tap again to restart the game. Click “Replay” to play the game again with the same initial positions of all the objects.
- 2. On a computer or tablet with a keyboard, use the arrow keys to jump left, right, up, or down. Alternatively, or if no keyboard is present or it affects the page in which the game appears (such as an ePub reader), click above the frog to

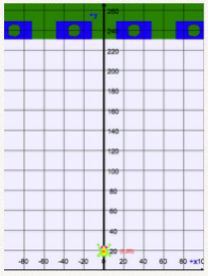
make it jump up, below it to make it jump down, and to one of its sides (but in roughly the same horizontal row) to make it jump left or right.

2.2 Physics used in *Physics Frogger*

Let’s dissect the frog...oh wait, this is physics, not biology...so let’s dissect the *Physics Frogger* game.

As they say in real estate investing, it’s all about “location, location, location.” Likewise, in physics, describing the motion of an object begins with specifying the location of the object, in this case the frog.

Figure 2.1 A 2-D Cartesian coordinate system used in *Physics Frogger*.



To specify the location of the frog in the game, we use a coordinate system. For example, Figure 2.1 shows the two-dimensional (2-D) Cartesian coordinate system used in the game, with the $+x$ direction defined to the right and the $+y$ direction defined upward, toward the top of the page.

A coordinate system is defined by:

- 1. an origin.
- 2. a scale, determined by the tick marks, numbers,

Fig. 1. Game *Physics Frogger* used for motivating coordinates systems in two dimensions.

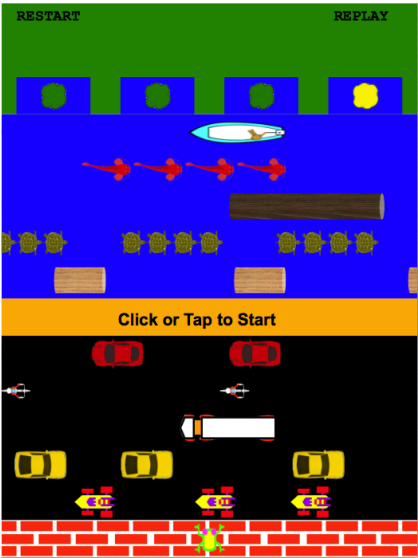


Fig. 2. Game *Physics Frogger* used for motivating coordinate system in two dimensions.



Fig. 3. Game *Physics Frogger* with chosen final position and scores.

After playing the game again with these three goals (which turns out to be somewhat more difficult than before), an advanced automatic play strategy is introduced that typically uses the minimum possible distances and times. An experienced gamer can perhaps also reach these optimum solutions, but only if she is patient enough to wait for the right alignments of objects and avoids even a single mistake while playing.

Finally, a third automatic play option is included in the game that allows an advanced user to program a custom algorithm, based on the utilities of the game described earlier in the text (such as the routine that specifies whether a given position is safe), and to test it, trying to reach even better scores. A later chapter, devoted to relative motion, revisits this game to make the reader notice that the frog should keep its horizontal velocity when jumping from one water object to the next. This physical property is not respected in this chapter and hence the physics in the classic Frogger game is not correct. An ultimate version of the game is provided to show how adding this feature affects gameplay.

4 Technical aspects of eBook creation

Writing a document with the length and complexity of a physics book (with several chapters, sections, images, formulas, cross-references, citations, etc.) requires a good typesetting program. Furthermore, we needed a program that was able to export the narrative in a form suitable for the creation of an electronic book.

We aimed from the very start to create an ePub document. ePub is the standard established by the International Digital Publishing Forum for the “distribution and interchange of digital publications and documents based on Web Standards” (IDPF, 2015). Thus, ePub documents can be read by most hardware and software platforms. Creating ePubs requires creating a self-contained digital file with a carefully prescribed internal structure that organizes all of the text, images, cascade style sheets (CSS) and other files—such as our games—in a book-like readable document. The text for an ePub must be written using XHTML. XHTML stands for eXtensible HyperText Markup Language and is a refinement of HTML, the World Wide Web Consortium standard (together with CSS) for building Web pages (W3C, 2015).

Unfortunately, XHTML is not a user-friendly language to write in, and creating an ePub without specialized tools is also far from trivial. For this reason we decided to use LaTeX to write the narrative and Pandoc to create the ePub. LaTeX is a de-facto standard and free document preparation system, very popular among scientists like us. It offers powerful tools for creating technical and scientific documentation, from a journal paper to a sophisticated book (LaTeX, 2015). Pandoc is a free conversion tool that can be used to convert LaTeX documents into ePubs with a more than reasonable quality (Pandoc, 2015). In particular, Pandoc respects the book’s original layout, images, and equations (generating MathML equivalents). The combined use of these two tools provided us with a way to create a professional-looking, complete narrative in the form of readable PDF and ePub versions of our book. However, neither version included playable games.

As mentioned earlier, we created the games using Easy Java/JavaScript Simulations. We list here the features of EjsS of interest for our work, but provide no details of the programming. EjsS:

- Has a simple yet powerful architecture for creating the logic of our games. Authors follow a left-to-right sequence of panels where they code their simulations.
- Allows coding to be done using the standard JavaScript programming language, which provides a great deal of flexibility for programming the sometimes-complex logic of games.
- Includes an easy to use solver for ordinary differential equations with support for events. Event handling is very useful for dynamic games.
- Generates advanced graphical and interactive interfaces based on standard HTML5 elements and scalar vector graphics (SVG), designed by the author using a drag and drop mechanism from a palette of existing view elements.

Because EjsS uses a high-level, standard structure for all of its simulations, EjsS allows effective sharing of our code with other authors, facilitating the inspection and customization of existing simulations. This possibility will be important if an instructor wants to use our games for teaching computational physics.

We improved the capabilities of EjsS to export several EjsS-generated simulations into self-contained ePubs. Since JavaScript and SVG are the W3C standard for programming and graphics, JavaScript EjsS simulations can run inside ePub documents. This new feature allowed us to effectively and efficiently create our games, and provided us with a second ePub document with all the games for the book.

We investigated several graphical designs for our games to find what would fit best into a playable ePub document. After several attempts, we decided to create the games so that they would cover 100% of the page's available space, with all text inside the game scene. (That is, we would not use standard HTML elements outside of a single drawing area. The main reason is that ePub readers can change the font size of HTML elements, confounding our interface.) Also, since the games may be played on a tablet or smartphone, we decided that all games should be playable with and without a keyboard. A player reading the eBook on a computer can use the mouse and the keyboard (if the game allows it), but a tablet user must be able to play the game by just tapping on the screen.

The final step required combining the two ePubs, one with the narrative and one with the games, into a single, final ePub. This task required us to use a specialized editor for ePubs, and we aimed for a free one. We chose Sigil (Sigil, 2015) because it allowed us to open the contents of both ePubs and include the files from the games ePub into the narrative ePub. However, we found the procedure too low-level, since it required some manual corrections in the procedure, including editing some of the simulation XHTML files to keep links among files. It also produced a very uncomfortable situation with equations written in MathML, since the version of Sigil that we used introduced extra characters when processing the MathML¹.

These inconveniences made us search for an alternative procedure to create our eBook. We then tried iBooks Author, Apple's free tool for creating iBooks, a proprietary format, based also on HTML and JavaScript, for specifying interactive electronic documents. iBooks Author can import our ePub narrative file and offers a number of Apple-specific widgets that provide sophisticated multimedia and interactive capabilities. The main drawback is that iBooks and ePubs that use these widgets only run properly on Apple devices using the MacOS X or iOS iBooks reader.

That was, however, the only drawback we could find! We added to EjsS a feature to easily export a simulation in the form of an Apple widget, compatible with iBooks Author. Once this new feature was added to EjsS, embedding our games into the final ePub or iBook document and editing the result for final fine-tuning was a delight. The final result had a look and feel of the highest quality.

5 Conclusions and plans for the book

Writing an eBook is quite an adventure, involving not only a lot of writing and revising of narrative, but also making many decisions on the goals, design, and contents of the book. We made our pedagogical decisions first and then studied the technical alternatives for our book, learning about the possibilities and sharpening our tools and skills as we proceeded. The result is an eBook, still in progress, that is both interesting and fun to create. We hope it is just as interesting and fun to read and play. Of course, our final objective is to entice and motivate our readers to learn the physics behind video games.

From the technical point of view, the tools mentioned in the paper, all of them free, comprise a valid combination for creating sophisticated interactive games and eBooks. We would however like to find an ePub editor that rivals iBooks Author in simplicity of use

1 There is a newer version of Sigil available since December 18th, 2015, but we haven't tested it yet.

and quality of results. We need one that creates electronic books with similar multimedia capabilities to an iBook and that can be read on any hardware and software platform.

The individual games will be available freely through the OpenSourcePhysics collection in ComPADRE as we build them, so that they can be inspected and possibly improved by others (<http://www.compadre.org/osp/items/detail.cfm?ID=13970>). The eBook will be made available electronically on-line, once finished, through channels still to be determined.

High school and college teachers in physics, math, or computer science may want to weave our eBook, or the EjsS games, into their instruction and class activities, including student projects, homework, and in-class exercises. We can envision teachers assigning chapters from our book to their classes and following up with questions, exercises, challenges, and exam problems. If our book is used with instruction in programming, then students can create their own games. A useful challenge is to think about how to automate gameplay to achieve the highest possible scores.

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Game-Based Learning for Supporting Self-Confidence and Motivation of Female STEM Students

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Many areas of STEM are influenced by gender related stereotypes. Studies report a lower self-concept of female students in most of the STEM subjects and lower interest, motivation, and class contributions in physics and the information and communication technologies (ICT). Subjects like physics and ICT are often perceived as "male" which puts them out of the focus of female students. This paper describes the concept and implementation of the Mit-Mut project, which applies aspects of game-based learning and gamification to STEM domains to promote positive self-concept and motivation of female students. The Mit-Mut game was designed to accompany class measures in school, particularly for female students in lower secondary school. Although the project mainly focuses on entrepreneurial skills and ICT, it has several connections to physics teaching. Results of the evaluation show that the game was able to improve the self-concept of students while the motivation for pursuing a STEM career did not increase significantly.

1 Introduction and Theory

Studies show that STEM (science, technology, engineering, & mathematics)-classrooms, particularly in the subjects of physics and information and communication technologies (ICT), are subject to stereotype related gender phenomena (Ertl, Helling, & Kikis-Papadakis, 2011; Jurik, Gröschner, & Seidel, 2013; Kessels & Hannover, 2008): they report gender differences with respect to students' academic self-concept in these subjects (Dickhäuser & Meyer, 2006; OECD, 2015), their motivation and interests (Jurik et al., 2013; Kessels & Hannover, 2008), as well as their classroom participation (Ertl & Helling, 2010; Jurik et al., 2013). These factors are known to have an impact on students' achievements (see OECD, 2015) and are therefore essential to consider when aiming at gender appropriate classroom teaching.

First of all, the *academic self-concept* is crucial for a student to realise one's own academic potential in a subject (see Jahnke-Klein, 2006; Marsh & Scalas, 2011). Results of the latest PISA study (OECD, 2015) indicate that differences in the outcomes of science scores between boys and girls can be explained by differences in their self-concept. Self-concept has implications for success and failure (Beermann, Heller, & Menacher, 1992). Even if girls and boys have the same grades, girls are less likely than boys to attribute success to their talent, and yet more likely to attribute failure to their lack of ability (Dickhäuser & Meyer, 2006). Such attribution patterns are detrimental to academic achievement (Heller & Ziegler, 1996; Steinmayr & Spinath, 2009) as they reduce the motivation for putting further efforts into a subject.

For this reason, several studies have emphasized the role of *motivation* (e.g. Dresel, Schober, & Ziegler, 2007) in earning appropriate achievements in a subject. According to expectancy-value theories (Eccles et al., 1983; Schlag, 2006), a reduced expectation for

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success in an area usually inhibits the motivation for further learning in this area and therefore leads to poorer outcomes. This is particularly important in the context of gender and STEM, because several studies report lower motivation in females in STEM areas (e.g. Ertl et al., 2011; Ihlen, 2009; Jurik et al., 2013).

Both, self-concept and motivation are often affected by stereotypes (Owens & Massey, 2011). Research on the *stereotype threat* describes how much mere presentation of a stereotype can influence students' achievements (see e.g. Owens & Massey, 2011). Stereotypes, particularly those of parents and teachers, can have a big impact on students' dispositions, especially stereotypes regarding females in science (Martignon, 2010). Evidence for that was provided by Nosek et al. (2009): In a cross-national study, these researchers were able to describe the aspirations of females in STEM in different countries in terms of their perception of STEM as a "male" domain in their respective countries. Girls consider subjects stereotyped as "male" as less relevant for their personal development (Schwarze, 2010) and female students with preferences for such subjects often experience negative consequences from their peer group (Kessels & Hannover, 2008). Kessels and Hannover (2008) argue that girls who like physics are seen as out of favor, less attractive and less feminine, and are therefore likely to lose interest in these subjects as their sense of identity develops. Consequently, support for females in STEM has to focus on the support of their self-concept, the enhancement of their motivation, and the overcoming of stereotypes.

As these discussions show, there is a special need for facilitating females' self-concept and motivation with respect to STEM subjects. It is necessary to allow students to develop their self-concept in a positive way (see Lazarides & Ittel, 2012). For this process of discovery, students should find themselves in a safe space that allows them to work on issues that are associated with challenges rather than with stereotypes (see Ertl, Luttenberger, & Paechter, 2014). Such activities may include hands-on activities that are focused on students (see Paechter, Jones, Tretter, Bokinsky, Kubasco, Negishi, & Andre, 2006), extracurricular learning activities to allow students to form professional experiences (Prenzel, Reiss, & Hasselhorn, 2009), and the involvement of role models that counteract stereotypes (e.g. Marx & Roman, 2002).

2 Concept and Implementation

This paper will present the concept and the implementation of game based learning to promote motivation and a positive self-concept of female students in lower secondary school. It will elaborate on situated learning scenarios as an approach for supporting girls' development of skills and discuss how these can counteract the development of stereotypes and enhance appropriate self-evaluations. It will present the implementation of the game-based learning didactics of the project Mit-Mut. Mit-Mut is an Austrian project dedicated to supporting girls' key qualifications and entrepreneurial skills in the ICT sector and has several relations to physics teaching.

2.1 Situated learning scenario

Situated learning scenarios can facilitate hands-on activities and support development of self-confidence. Such environments often apply aspects of the *anchored instruction* approach that was developed by the Cognition and Technology Group at Vanderbilt University (CGTV, 1990) to support students in mathematics. Using learning technologies, the anchored instruction approach provides students the setting of a role play game with particular tasks to solve. It uses narratives to transfer learning contents from the classroom with stereotypical attributions of abilities in mathematics and physics to a (fictional) scenario with realistic problems. It departs from structured classroom lectures to evoke and facilitate self-directed and problem-oriented learning to allow students to discover their own abilities. Starting from the problems presented in the narrations, students should be able to develop their problem solving skills and to transfer them to further situations and problems.

The original anchored instruction approach was implemented by the Jasper Woodbury

series and consisted of several video episodes that included mathematical and physical issues for grades five to eight. These dealt with a ranger called Jasper Woodbury who had to master several challenges, e.g. saving a bald eagle or coming home with a broken boat. At the end of each episode, students are challenged to help Jasper solving his problem. Research emphasizes seven design principles as important for anchored instruction (see CGTV 1992); for the context of Mit-Mut we will focus on these five:

- The *Video-based format* aims at presenting the issues comprehensibly and emotionally and thereby promotes students' identification with the protagonist and their engagement in the problem solving process.
- A *narrative format of presentation* allows displaying authentic real-life problems and the applicability of the skills developed for new situations.
- The *generative format* provides connections to students' experiences and prior knowledge and encourages them to find an ending for each episode.
- The learning materials consist of *complex problems* that include several sub-problems to be solved.
- Furthermore, the episodes establish *links across the curriculum*, e.g. by including the concepts of velocity and distances from physics or business cases from economics.

Several of these principles can be found in game based learning approaches (see Günther, Mandl, Klevers, & Sailer, 2015) while other aspects of gamification go beyond the situated learning scenario.

2.2 Gamification approach

While situated learning scenarios emphasize the learning design, gamification approaches focus on learners' needs. Many gamification approaches relate to Deci and Ryan's (1992) self-determination theory on motivation and try to establish flow (according to Csikszentmihalyi, 1985) by fulfilling these needs. Deci and Ryan (1992) identify three basic needs for motivated and self-directed learning: *autonomy*, *competence*, and *relatedness*. Gamification approaches derive several game mechanisms from these basic needs, e.g. feedback, personal profiles, transparency of results, goals, competition, and collaboration. Günther et al. (2015) discuss how well these mechanisms could satisfy basic needs and which particular game elements, e.g. high scores, badges, achievements, avatars, and of course the game story, are appropriate to implement the game mechanisms (see Günther et al., 2015). This implies the application of several of these mechanisms in combination with the situated learning scenario.

2.3 Concept for the Mit-Mut game

The concept for the Mit-Mut game is to apply an anchored instructional learning scenario enriched with gamification elements. To offset common gender-specific norms in the classroom, the game was dedicated only to girls. A particular focus of the game was the aspect of social inclusion, which was implemented by a community (according to Lave and Wenger, 1991) of students, role models, teachers, and the Mit-Mut team in the style of a *social enterprise education entertainment network* (Se³N).

In accordance with many established theories about females in STEM, the *didactic design* focused particularly on facilitating students' discovery of personal skills and key qualifications to overcome stereotype skill attributions. Consequently, the design aimed at learning situations that allowed students to experience self-efficacy to support the development of a positive self-concept with anchored instruction as a didactic approach. This includes an authentic context by video messages as well as the interaction with role models. As the development of a positive self-concept in the subject area is a key aspect of the game, it was designed to offer experiences of success as well as to give differential and supportive feedback by the Mit-Mut team and the role models in the Se³N. In particular, the interaction with role models can allow students to overcome missing experiences in socialization. It helps students find appropriate attribution patterns of their own skills

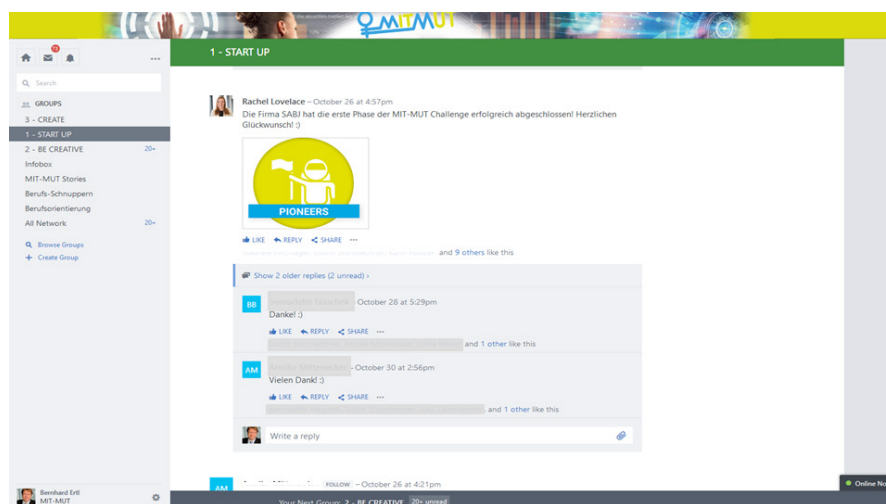


Fig. 1. Screenshot of the Se³N.

and abilities beyond stereotypes—an issue that is particularly important in the context of STEM subjects.

Mit-Mut included particular aspects of gamification to evoke students' perception of playing, unlike performing school project work. These aspects are introduced by the provision of badges and achievements as well as by the inclusion of gaming apps as incentives.

2.4 Implementation of the Mit-Mut game

The Mit-Mut game had an anchor story about a CEO from Silicon Valley, called Rachel Lovelace, who came to Austria to open a local branch. She was looking for a team of motivated females that would help her company find an entry to the Austrian market. For this reason, she was asking groups of students to develop an idea for a mobile phone app. Rachel was communicating to the groups by video messages or via the comment/chat function of the Se³N. The game consisted of five phases of project work and four mini games between these phases. In total, the game was designed to be a 6 week class project with an estimated two lessons per week. A teacher handbook completed the game materials.

2.4.1 Social enterprise education entertainment network (Se³N)

The Se³N was the core element and interface of the game. It was implemented in the platform Microsoft YAMMER (see figure 1) and supported interaction between the students. Thus, it served as an interaction and communication platform within the game, collected students' project work, and provided access to the mini games as well as information about professional development.

2.4.2 Project work

The project work of the game comprised five project phases that could be accomplished in the classroom or at home: A *start-up* phase in which the students formed groups and developed a logo for their company, a phase for inventing an idea and a concept for their app, called *being creative*, a phase for developing a paper prototype of the app called *create*, a phase for preparing a video presentation of the idea and the app, called *present*, and a phase for voting for the best app and earning the achievements called *achieve*. Each project work phase was introduced by a video message by Rachel posted in the Se³N and

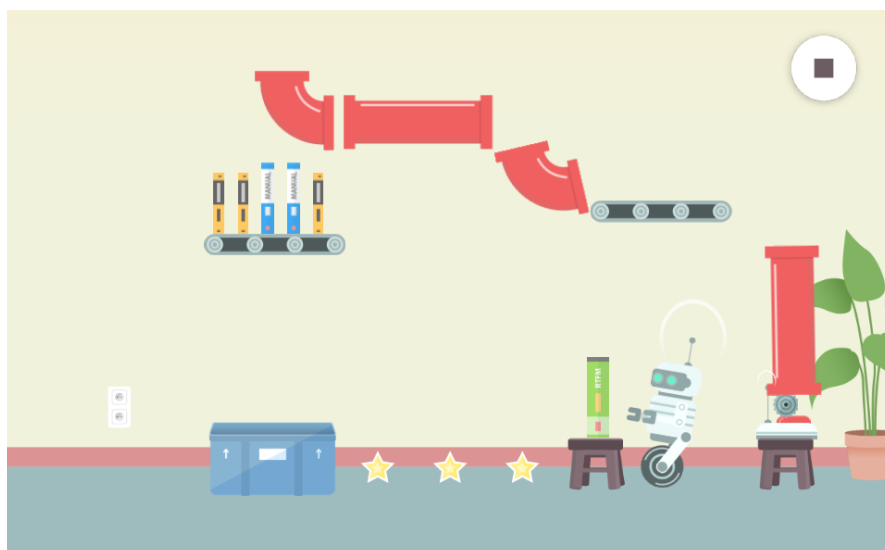


Fig. 2. Screenshot of the physics mini game.

by links to supporting items for each phase. The teacher handbook also provided materials for facilitating project work in the classroom.

2.4.3 Mini-games and further gamification elements

Between these phases, the game included four mini-games in the style of gaming apps. These mini-games consisted of different levels and were designed to motivate students by providing incentives. All of the games dealt with issues important for female entrepreneurs, e.g. taking up aspects of work-life balance, computer security, analytic thinking, or problem-solving issues. Figure 2 gives an example of the mini game that dealt with problem solving in the domain of physics. The particular problem was to use a wheel that dropped from the top to solve a challenge. The wheel was either a car wheel with a rubber tire or a gear wheel out of iron. Each kind of wheel followed the respective laws of physics concerning gravity, acceleration and bouncing behavior. Students had some utilities like tubes, springs, and slides which they could arrange and rotate freely to build a course for the wheel. During this course, students were able to collect stars for earning an extra bonus. In the level shown below, students had to bring the green book into the blue box. They had a small gear wheel (lower right) that had to be used to hold down the remote control of the robot to push the book on the stool until it fell into the box (in order to collect the stars). The particular challenge of this course was to keep the wheel on the remote control for the robot and prevent it from rolling down. This could be accomplished either by positioning the tube as shown in the figure to fix the wheel in place, or by finding ways to reduce its spin. Core concepts of the game, e.g. problem solving strategies in the physics game were intended to be reflected with the teacher in the classroom. High scores of the mini games were posted in the Se³N. Furthermore, students were able to earn badges and achievements, e.g. for postings or results of the project phases.

2.4.4 Teacher materials and classroom reflection

The aspects of the mini-game, the project progress, and career opportunities were intended to be reflected in the classroom. Therefore, the project provided an elaborate teacher manual that contained information and methods for supporting the groups during their project and for reflecting the mini games. Furthermore, the manual provided teachers with aspects essential for gender appropriate teaching in STEM, e.g. gender phenomena, attribution patterns etc.

		before		after		t-Test		
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>t</i>	<i>p</i>
Skills	planning	1.94	0.802	2.11	0.936	35	-1.063	n. s.
	communication	2.14	1.141	1.80	0.797	35	1.555	n. s.
	presentation	2.29	0.938	1.97	0.870	35	2.149	.039
Motivation		2.98	0.835	2.97	1.027	35	0.062	n. s.
Self-concept	scale	2.33	0.725	2.22	0.742	35	0.790	n. s.
	ability	2.91	0.951	2.49	0.951	35	2.266	.030

Tab. 1. Means, standard deviations, t- and significance values with respect to skills, motivation, and self-concept. Lower means indicate better results.

3 Objectives and Assessment

The game ran from September to November 2015 in the lower secondary classes (ages 13-14) of 9 Austrian schools. Originally, 15 schools agreed to participate in the game. However, after the summer break, several schools struggled with the integration of refugees, leaving them with reduced resources for the game or even resulting in them dropping out entirely. Ultimately, 9 schools remained and in total 79 students built 20 teams. Students participated in the Se³N and provided between 0 and 144 postings (*M* = 13). They created 17 logos for their company (phase 1), invented 16 concepts for their apps (phase 2) and provided 15 paper prototypes (phase 3). However, they found the video presentations quite challenging and so only 10 groups provided them (phase 4). 16 votings in phase 5 indicate that 80 per cent of the groups finished the game. To analyse of the effects of the game, students were asked to fill in a questionnaire before and after the game. 50 students filled in the first questionnaire, 44 students filled in the second, and 35 students filled in both questionnaires. In the following, the instruments will be described and the results will be presented and discussed. The Mit-Mut game ended recently and therefore we can only present parts of the analysis.

3.1 Instruments

The questionnaires each consisted of a self-evaluation of skills, an estimation of motivation, and a measurement of students' self-concept and took place before and after the game. Students estimated the level of their own skills with respect to planning, communication, and presentation on a scale from 1 to 6 with 1 as strongest value. To evaluate students' motivation, a scale of intrinsic and extrinsic motivation for STEM professions, with 7 items was applied (Ertl et al., 2014). The reliability of the scale was good (Cronbach's α = .852 before and α = .912 after). With respect to students' self-concept, a scale of Dickhäuser, Schöne, Spinath, and Stiensmeier-Pelster (2002) was adapted for computer and media. The reliability of this scale was also good (Cronbach's α = .887 before and α = .898 after).

3.2 Results

The results of the study highlight different points. Regarding the self-evaluation of skills, students showed a statistically significant improved self-estimation of their presentation skills, an statistically insignificant higher self-evaluation of their communication skills, and an statistically insignificant decrease in the estimation of their planning skills (see table 1). Regarding their motivation for STEM professions, the analysis couldn't reveal differences on a statistical level and regarding the self-concept, there was a slight (but not significant) increase with respect to their academic self-concept. Nevertheless, students had a significantly higher estimation of their ability (which related to one item of the self-concept scale).

3.3 Limitations

Mit-Mut was designed as a long-term field study and depends on implementation across different schools. Unfortunately, there was a dropout of schools that resulted in a low number of participants. A higher number would have been desirable in order to obtain deeper knowledge about the impact of the game. Another obstacle was that Mit-Mut was specifically dedicated to females to prevent dysfunctional gender specific interactions and norms in classroom during the game (see Ertl & Helling, 2010; Kessels & Hannover, 2008; Jurik et al., 2013). This had the consequence that teachers had to care for an alternative program for male students which may have resulted in some specific teacher behavior, e.g., cutting time for game. Greater insight into how both aspects may have hindered game implementation are expected by the qualitative study that is currently being conducted.

3.4 Discussion and consequences

Bearing in mind the obstacles described above, the Mit-Mut game could demonstrate effectiveness in aiding students' self-estimation of presentation skills and could help improve their self-concept in the field—which is much more important in the context of the theory described above. Given the results from OECD (2015) and Nosek et al. (2009), this is a first important step towards increasing females' motivation for STEM subjects. Contrary to our expectation, the game did not yet have an impact on student's motivation for working in a STEM area (even if answers to open questions indicated they found the game itself motivating). The academic self-concept is an essential aspect for the development of interests (Eccles et al., 1983; Lazarides & Ittel, 2012) and it may be that the paths toward motivation postulated in the respective models (e.g. Eccles et al., 1983) need some time to develop. Furthermore, one has to consider that females in the age of 13-14 are not yet in the age to make professional decisions and thus may not have realized the relevance of the game to their own future career. Nevertheless, the game showed a significant effect on the self-concept of the female students in a stereotypically male domain and therefore it can serve as a prototype to gauge success in counteracting gender stereotype ability attributions.

Acknowledgements

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Evaluating the Use of Flight Simulators for the NASA/AAPT “Aeronautics for Introductory Physics” Educator Guide

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Airplanes are fascinating to students. The question of how airplanes fly is frequently asked of teachers and parents, but neither U.S. nor European textbooks cover the topic in depth. Many educational resources provide oversimplified or erroneous explanations that lead to misconceptions about flight and fluid dynamics. Building on the NASA/AAPT joint project “Aeronautics for Introductory Physics” educator guide (Vieyra, Genz et al., 2015), we are developing and evaluating a laboratory experience to elicit, confront, and resolve student misconceptions about flight. To do this, we use a commercial off-the-shelf flight simulator game (XPlane10), a mobile app (WindTunnel), and a wind tunnel lab (Leybold 37306). Students receive a simulated flight lesson with visualized forces and smoke trails, observe fluid flow around an airfoil on the app, and perform a lab experiment with the wind tunnel. Students then explain their observations in a report and link it to theory and experimental results from the wind tunnel.

1 Introduction

Misconceptions in fluid dynamics are widespread in society and have great impact on engineering design of everyday items such as cars and aircraft, economic consumerism, and, ultimately, even fuel efficiency and ecological impact. A wide variety of misconceptions abound, from misunderstandings in aerodynamic shapes to the misapplication of Bernoulli’s principle to the concept of flight. In section 4, we elaborate further on such misconceptions in detail.

Fluid dynamics is an increasingly important topic in a globalized economy that is strongly based on international transportation of people and goods. Despite its significance for society, fluid dynamics is often relegated to middle school textbooks, and tends to fall into the gaps between more thoroughly studied disciplines such as kinematics and thermodynamics in high school. As a result, it is frequently overlooked. Although flight concepts are sometimes addressed in aeronautical, military, and scouting organizations outside of the classroom environment -and even there, the physics of flight is often taught erroneously. Students are not seldom taught that Bernoulli’s Principle is the only or primary cause for lift of an aircraft, a superficial understanding that ignores the unique behavior of real fluids. Furthermore, when taught in the context of forces and free body diagrams, illustrations are often deceptive or inaccurate, showing lift to be vertical in most scenarios. Students are left with the impression that fluid dynamics is inherently counterintuitive and oversimplified. These are only a few examples of the widespread shortcomings of textbooks. The result is that students settle with simple but unsatisfactory explanations which are then parroted in test responses, and teachers have a hard time to help students to think critically about the practical application of concepts that involve fundamental physics.

Genz, F., & Vieyra, R. E. (2016). Evaluating the Use of Flight Simulators for the NASA/AAPT “Aeronautics for Introductory Physics” Educator Guide. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 139–148). Mulhouse: European Physical Society.

The lack of good explanations concerning the physics of flight in textbooks has several reasons. Solving the Navier-Stokes equations in classrooms is too difficult for young students. Moreover, the computing power that is necessary for simulations has historically been inaccessible to classrooms. Thus, over-simplifications dominating physics textbooks often make dubious use of Bernoulli's Law (Weltner & Ingelman-Sundberg, 2003). Furthermore, teachers can almost never explore the context by real flight experience with a class of students. Flight simulator games, on the other hand, provide the necessary computing power and can serve as a context that is easy to exploit in classroom. It encourages students to generate questions ("What if I vary the wing shape?", "I wonder if it is possible to perform a loop with a Jumbo jet", or "Is the simulation's behavior now realistic?"), and lets students build their own mental models about what causes an airplane to fly.

1.1 The importance of fluid dynamics for the global community

Climate change is hugely driven by the transportation industry and globalization. In 2013, the greenhouse gas emissions of the transportation industry, alone made up 27% of the U.S.' carbon output (EPA, 2015). Globally, over 36 gigatons of CO₂ were produced from the burning of fossil fuels in 2013, with about 7 gigatons (or about 20%) coming directly from the transportation industry –an increase from only 2.8 gigatons in 1970 (IPCC, 2014). In a world and an economy that is heavily dependent on the increasing efficiency of transporting goods, developing a solid intuition for aerodynamics is integral. Incremental progress in engineering is not enough to reduce environmental damage either now or in the future. Breakthroughs in engineering and fluid dynamics are crucial for sustainability. Moreover, the design of power stations, the medical understanding of blood flow, and the analysis of pollution flow heavily depend on fluid dynamics. Not surprisingly, the Clay Mathematics Institute lists the Navier–Stokes existence and smoothness problems as one of the seven millennium problems in mathematics with a \$1,000,000 prize for a solution or a counter-example.¹

2 Concept

At the Physics Education Department of the University of Cologne we have created a module on the physics of flight in our teacher preparation courses with the hope that this will be a first step toward attaining three key goals for tackling the world's economic and social challenges:

- Improve the quality and quantity of fluid dynamics education in schools.
- Attract talented students to fluid dynamics at an early age.
- Connect scientists with young talent to inspire both sides.

Ultimately, these goals can only be achieved by first working with pre-service teachers to enhance their own understanding about flight, and for them to internalize the value of flight physics in schools. This is done by teaching a module that encourages the pre-service teachers to elicit, confront, and resolve their own misconceptions about flight. The practical implementation of these goals is based on three pillars (also see sections 3.1, 3.2, 3.3, and 3.4):

1. Students collect virtual experiences in a flight simulator game and through an interactive 2D fluid flow app.
2. Students conduct an inquiry lab with an educational wind tunnel.
3. Students' conceptions about flight physics and fluid dynamics are collected before and after the lab.

Furthermore, feedback is provided to the student group. The flight module we chose to implement in our pre-service courses is founded on the NASA/AAPT joint project "Aeronautics for Introductory Physics" educator guide (Vieyra, Genz et al., 2015), a freely downloadable e-book filled with dozens of laboratory experiences and activities for the introductory

1 <http://www.claymath.org/millennium-problems> [2016-03-03 15:14]

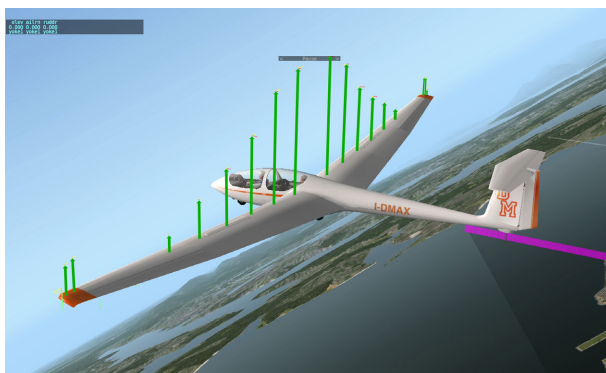


Fig. 1. X-Plane 10 screenshot with one visible flight model (here: forces acting on the wings) and flight path visualization (purple).

physics student (middle school through early university). This e-book was co-authored by experienced teachers, pilots, aeronautical engineers and an astronaut specifically for teachers who have never taught fluid dynamics (or other flight-related physics) before. The book has a logical structure as well as prepared lesson plans and worksheets. One of the main goals of the book is to help students to empirically understand the cause of lift, and to dispel with the popular but erroneous models that rely exclusively upon Bernoulli's principle. In using these resources and lab experiences, we also incorporated two virtual components: the flight simulator and the wind tunnel app. The idea to incorporate gaming into lab experiences is based partly upon science education research done through the Educational Gaming Environments (EdGE) Project at TERC, which suggests that casual games bridged with in-class learning (or "blended learning") results in greater student gains than those seen in students asked to play outside of class without directly connecting their games to the course content (Rowe, Asbell-Clarke, Bardar, Kasman, E. & MacEachern, 2014).

The activities we chose to undertake at the university embrace inquiry experiences under the guidance of a laboratory assistant, and do away with classic cookbook labs. Techniques for improving teachers' understanding are more successful when there is direct focus placed on inquiry as a core component to the nature of science (Burgin & Sadler, 2016; Ledermann, 1992). In these studies, the role of the laboratory teaching assistant shifts away from that of a technical assistant and towards that of a constructive but critical reviewer. In this scenario, the assistant must ensure that enough support is provided so as to not overwhelm the student group with the possibilities; overly ambitious ideas must be simplified. Moreover, the strategy focuses on fostering an expert-like understanding of the methods and procedures of a scientist. Improving the students' understanding of scientific methods and scientific thinking is an often demanded but rarely achieved goal: "Science teachers do not possess an adequate understanding of the nature of science, irrespective of the instrument used, to assess understandings" (Ledermann, 1992, p. 335). Recent research from the AAPT and the Kansas State University (Madsen, McKagan & Sayre, 2015) suggests even that traditional, instruction-based teaching in physics introductory courses spoils scientific thinking.

This approach to teaching the physics of flight through inquiry and attention to the nature of science is integral to helping pre-service teachers (and thereby their students) to elicit, confront, and resolve their own misconceptions about the topic. Using this approach, "Aeronautics for Introductory Physics" accompanied by the virtual experiences allows students to deconstruct their own thinking and gives them the freedom to challenge the overly simplistic and unsatisfactory explanations found in textbooks as they develop their

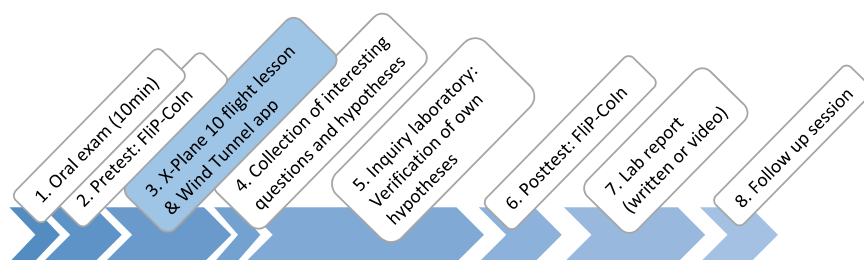


Fig. 2. Roadmap for the laboratory module.

own mental models about how flight occurs.

2.1 Chronological overview of the laboratory class

After a short oral exam to ensure the student group's preparation, every group member fills out the newest version of the Flight Physics Concept Inventory (FliP-Coln, see section 3.4.1) as a pre-test. The student group then takes turns with flying the virtual flight lesson (see section 3.1) and with an interactive 2D simulation app – we used the app Wind Tunnel (Algorizk, 2015), but multiple similar apps are available. This is done primarily to foster self-motivated questions in the students' minds and for the affective learning outcomes (see section 2.3: Goal #2), which are often neglected (Brownell et al., 2004; Shephard, 2008). Self-formulated hypotheses about flight that have been generated by the virtual experiences can then be tested instantly in the experimental setup (see section 2.2: Goal #1). The students document their results in a written lab report or a video report. Afterwards, they take the FliP-Coln post-test. Finally, feedback to the lab reports is provided and the FliP-Coln results are shared with the students in a follow-up session.

2.2 Goal #1: Improving the quality and quantity of fluid dynamics in schools

Although fluid dynamics and flight physics have traditionally been treated as peripheral topics in schools, however this need not be the case. Fluid dynamics can be used to enhance and supplement a standard curriculum sequence of mechanics, from kinematics to energy conservation. It was with this sequence in mind that "Aeronautics for Introductory Physics" was written. To improve the quality and quantity of fluid dynamics in schools by making this resource accessible to teachers in Germany, we are translating the "Aeronautics for Introductory Physics" educator guide into the German language.

To improve teacher education, a three-hour-long pilot lab class was implemented into the "Physikalisches Praktikum für Fortgeschrittene" (advanced laboratory class) at the Institute of Physics Education of the University of Cologne. The lab class is based on three pillars:

- Virtual Experiences through simulations: "X-Plane 10" (by Laminar Research) and "WindTunnel" (by Algorizk) (see sections 3.1, 3.2)
- Inquiry Laboratory: Open wind tunnel and lab report (see section 3.3)
- Data Collection: Pre/post testing with the "Flight Physics Concept Inventory" (see section 3.4.1), as well as self-assessment of the lab reports and external feedback in comparison (see section 3.4.2)

2.3 Goal #2: Attracting talents for fluid dynamics at an early age

Children are naturally amazed by flying objects. This amazement is rapidly lost when confronted with faulty, oversimplified, math-based and often pedagogically poorly prepared explanations in school. The topic is rarely covered in depth by textbooks, and almost never by teachers. For many reasons (see section 1.1), an effective school curriculum in fluid

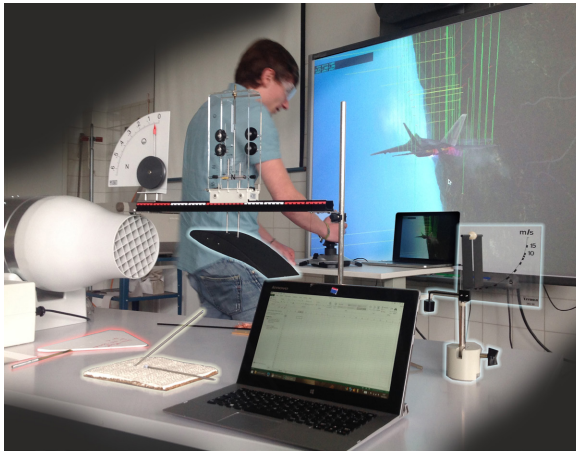


Fig. 3. Lab class setup: X-Plane 10, WindTunnel app and modified open wind tunnel setup based on LD Didactic P.1.8.6.2 (emphasized elements from left to right: delta wing, self-created airfoil, standard airfoil profile, anemometer).

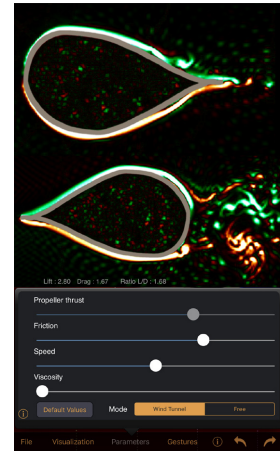


Fig. 4. Screenshot of a 2D wind tunnel app with curl visualization and adjustable parameters.

dynamics is crucial to tackle global 21st century problems. Scientification² of computer games, which are already popular, has the potential to meet scientific and pedagogical demands while simultaneously fostering student motivation (see section 3.1, 3.2).

2.4 Goal #3: Connecting scientists with young talents to inspire both sides

Connecting scientists with students via work on simulations can create a win-win situation for both parties. The student who has little initial knowledge or who has just learned about the established concepts in aerodynamics automatically focuses on the weak points of the theory or the scientist's understanding. Scientists seeking new concepts or inconsistencies in the theory can take inspiration for further research in these questions. Simulations are a good mediator between the two parties because they are easier to modify than real-world experiments. Of course, simulations also generate further questions (such as "Is this behavior realistic?"). This can also be seen as an advantage because it evolves scientific discussion. To connect researchers with young talent, the concept will be embedded into a university-wide teaching laboratory network which invites scientific researchers into the learning labs. This way, the ZuS project is building up four so-called Competence Labs (Science Lab, Media Lab, Social Lab and Language Lab). In the ZuS³ project, school classes are invited to these external learning places where pre-service teachers are trained to improve their teaching. The participating scientists will get the opportunity to train the pre-service teachers but also get support and learn from them. Moreover, the scientists can interact directly with the school classes invited to the Competence Labs.

3 Implementation

Based on the goals listed above, the following implementations have been undertaken:

3.1 Pillar A1: Virtual Experiences through Simulations: X-Plane 10

² Not to be confused with "gamification" of pedagogical content or "serious games"!

³ Zukunftsstrategie Lehrer*innenbildung (ZuS), University of Cologne: A project funded by the Federal Ministry of Education and Research, Germany.

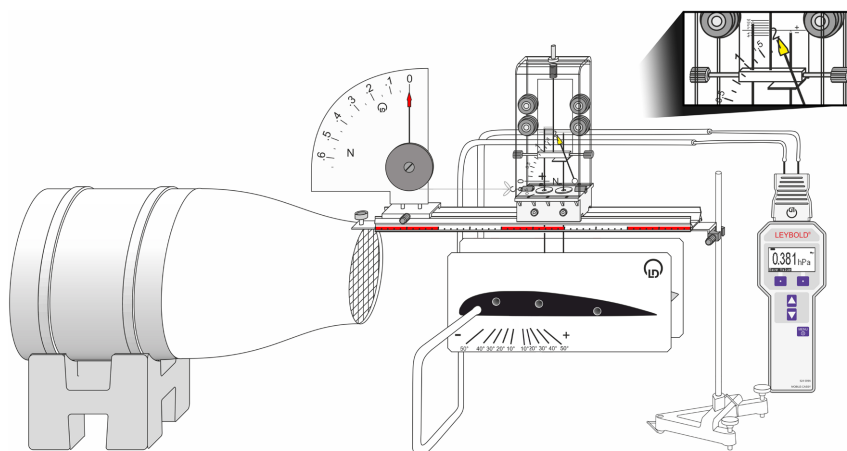


Fig. 5. Modified experimental setup (based on LD Didactic P1.8.6.2), schematically.

X-Plane 10 can display 3D data about airflow (such as velocity and acceleration) and forces acting on the airplane in real-time (referred to as ‘Blade element theory’⁴). Pairs of students receive a 15 minute flight lesson: Take-off, level flight, slow flight with full flaps, acceleration back to cruise speed and an approach for a landing back on the airfield are all included in this lesson. One student acts as a pilot flying; the other observes the patterns of airflow during maneuvers. They are expected to describe and explain their observations in a written lab report or video report and link their findings to theory and the results of the wind tunnel experiment.

3.1.1 Blade element theory (BET)

X-Plane 10 differs from most flight simulators in that it does not work with experimentally determined coefficients (i.e. stability derivatives, SD) but calculates the forces and momentums on the plane in real-time. Thus, the airplane’s wings are divided into many small parts and the forces are calculated for each “blade” several times per second. For physics students, this completely empirical approach is of special interest since it allows a purer method with which to test theory than SD-based simulations. Another important way in which X-Plane 10 differs from other flight simulators is that it comes with a built in airfoil builder which allows students and engineers to develop their own hypotheses and test the results of aircraft quirks, design flaws and completely new concepts.

3.2 Pillar A2: Virtual Experiences through Simulations: 2D wind tunnel apps

Realistic flight simulators have their strengths in closing the gap between scaled-model experiments and the real world; they also excel in motivating students, but they remain complex. To teach the basic physics of flight, another tool is needed. Interactive two dimensional wind tunnel apps can help to visualize fluid flow and allow for the control of many parameters sequentially (i.e. viscosity, friction, speed). Suitable apps let students vary the angle of attack during the simulation and automatically calculate the drag and lift of self-constructed airfoil profiles⁵. Moreover, it becomes easier for students

- to realize their own misconceptions,
- to discover shortcomings of the simulation, and
- to make comparisons to classroom experiments (see section 3.3).

4 <http://www.x-plane.com/desktop/how-x-plane-works/> [2016-03-19 19:25]

5 for example „Wind Tunnel CFD“ by Algorizk

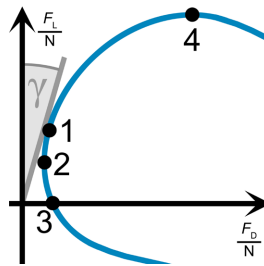


Fig. 6. Airfoil profile drag polar, schematically: best gliding angle γ , point of best gliding (1), lowest drag (2), zero lift (3), maximum lift (4).

3.3 Pillar B: Inquiry Laboratory

The setup for the real-world experiment is based on a modified open-wind tunnel setup from the Leybold science education supplier (LD Didactic: P1.8.6.2). If necessary, a much less robust (but workable) model can be built using a leaf blower, as described in “Aeronautics for Introductory Physics” (Vieyra, Genz et al., 2015). The key parts of the Leybold wind tunnel are as follows:

- An Adjustable fan
- An Airfoil profile
- A Drag and lift dynamometer with angle of attack scale
- Materials for modifying the airfoil (e.g. winglets)
- Materials for shaping own airfoils (e.g. cardboard, modeling clay).

After the Flip-CoIn pretesting and the virtual flight lesson, the student group is encouraged to formulate interesting questions as well as realistically verifiable hypotheses (e.g.: Which angle of attack results in minimal drag? What angle gives the highest lift to drag ratio? How big is the effect of winglets? Does the surface material have an influence? How big is the (negative) stall angle?). Without the assisted virtual flight lesson in the beginning of the experiment many of these questions do not come naturally to students and remain externally motivated. After the virtual flight lesson, the group needs to decide which of their self-generated hypotheses they want to test with the given experimental setup (see Fig. 5). To support later analysis, drag polar diagrams (see Fig. 6) are introduced to the students in the preparation materials. Students usually compare a standard airfoil with a modified airfoil and/or a self-created airfoil. This way, the lab reports become very unique and, thus, hard to copy. Feedback to the lab reports (written or in video form) is provided by oral and written comments as well as a standardized grading rubric (see section 8.1). For a successful lab report, the first priority is not to prove or verify the individually formulated hypotheses perfectly, but rather to critically point out errors, and sketch an outlook for further research. This way, the focus shifts even more towards the nature of science (NoS) and conceptual change.

The next sketch shows an infinitely wide airfoil profile from the side.

Let “ \bullet ” be an air particle above the airfoil at time = 0 s (respectively, \bullet =0.1 s; \bullet =0.2 s)

Let “ \bullet ” be an air particle under the airfoil at time = 0 s (respectively, \bullet =0.1 s; \bullet =0.2 s)

Draw the position of the air particles for time = 0.3 s, 0.4 s, ..., 2.5 s (with a red and blue pen).

Label the air particles with their times.



Fig. 7. Example task from the Flight Physics Concept Inventory (Flip-CoIn).

3.4 Pillar C: Pre-/post testing and feedback

Feedback and self-assessment is one of the most powerful influences on learning (Hattie, 2009). For this reason, we developed a criteria and feedback rubric for the lab reports (see section 3.4.2) and the “Flight Physics Concept Inventory” (FliP-CoIn). The remaining misconceptions –but also learning gains– are discussed with the student group in a follow-up session.

3.4.1 The Flight Physics Concept Inventory (FliP-CoIn)

The depth of understanding in fluid dynamics and conceptual change is assessed with the help of the “Flight Physics Concept Inventory”. The development of this assessment tool is done in close collaboration with the new laboratory class (see section 2.1). The questions and tasks were generated from:

- a) the most common misconceptions observed in literature,
- b) discussions during the lab classes,
- c) direct student feedback, analysis of the lab reports and
- d) interviews with advanced physics education students and experts.

3.4.2 Criteria and feedback rubric

Each lab report is rated with a standardized criteria and feedback rubric for lab reports (see Appendix). Simultaneously, the lab report is self-assessed by each student. Almost exclusively, the differences in perception are subject to the later follow-up session with the laboratory assistant.

4 Assessment and results

The most common misconceptions that were found among the ten graduate students of physics education with the help of the FliP-CoIn and analysis of the lab reports are listed below:

- The wing’s shape/Bernoulli’s Law/Newton’s 3rd law alone causes lift.
- Bodies with pointy front/sides are most aerodynamic.
- Persons inside a stalling plane must experience weightlessness.
- Air flows from above and under the wing cross each other undisturbed at the trailing edge.
- The air flow over the top side of a chambered wing is slower than / as fast as the flow below the airfoil.

Further misconceptions were documented during the simulation usage at one laboratory class session:

- Lift is always vertical.
- Angle of attack is identical to pitch.
- Glide angle/flight path angle is identical with angle of attack.

Based on the lab reports and the FliP-CoIn post-test we can conclude that no student resolved all of their initial misconceptions, but most are more aware of the existing misconceptions and those they have themselves. The qualitative, free-response FliP-CoIn post-test answers were often more sophisticated and demonstrated less assertiveness about their initial misconceptions, which we interpreted as a first step towards a conceptual change. Full replacement or modification of the initial mental model was generally not observed. Based on the lab reports, it is striking that all misconceptions which came up during the flight simulator were not only elicited, but seem to have been resolved. However, since we did not directly test for this, further research is necessary.

4.1 Affective aspects

Many students reported feeling more motivated than in other lab classes. Some students also reported feeling relatively unsettled with so much unusual freedom at the beginning. One student admitted to being more insecure about fluid dynamics than before, but added

that she had increased her understanding of the subject overall. Both laboratory assistants reported having more intrinsic motivation themselves. One laboratory assistant counted more than twice as many student questions directly addressed to him during the contact times than in other lab sessions. The same laboratory assistant also claims to have observed more student interaction and discussion, especially during simulation usage.

Both laboratory assistants emphasized that the 3D flight simulation is particularly useful for generating student questions. One also mentioned that X-plane 10 is implicitly teaching flight vocabulary. The 2D wind tunnel app seems particularly good for reducing complexity and for visualizing flow. The other laboratory assistant mentioned that the 2D wind tunnel app is useful for critical reflection of the simulation limitations because it is so similar to the experimental setting.

5 Conclusions and Outlook

Our preliminary experiences with the flight physics module in the pre-service laboratory course using simulations was very positive. With the simulations and tests implemented, the pre-service teachers were better able to elicit their misconceptions, as well as to confront and resolve some of them through the learning module. Results from the initial and final tests using Flip-CoIn as well as observational evidence and interviews with the pre-service teachers suggested that the participants benefited from the combination of virtual and hands-on laboratory experiences. With the results, additional work became necessary to implement the newly discovered misconceptions into the Flip-CoIn as a diagnostic tool on perceptions of fluid dynamics. Also it became obvious that it was necessary to create more explicit support for integrating simulations into Aeronautics for Introductory Physics. Since our results indicate that one lab session seems too short to resolve all misconceptions in basic fluid dynamics, we will look for a broader approach with more time and also evaluate the students' preparation and preparation materials. We encourage the reader to try these activities in pre-service or introductory physics courses, and to emphasize the importance and value of this often-overlooked topic. Although this test population was quite small, it became clear that fluid dynamics is an area overdue for physics education research.

Acknowledgements

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Appendix: Criteria and feedback rubric

The criteria and feedback rubric was developed, evaluated and modified by the laboratory instructors working at the Institute of Physics Education of the University of Cologne in several design circles. The newest German version can be requested by e-mail at florian.genz@uni-koeln.de. Fig. 8 pictures a rough overview of the structure, categories and grading ratios used for the English reader:

Criteria and feedback rubric for lab reports								
Relative weight:			Grade					
	Criteria:	very good (=1)	A	B	C	D	E	minimum standard (=D)
	Paedagogical presentation and model building							
10%	Motivation	<Definition of the threshold to grade A>						<Definition of the threshold to grade D>
10%	Model representation
	Remarks:							
	Structure and assembly							
10%	Scientific content
10%	Layout & writing style
10%	Presentation of results
	Remarks:							
	Scientific working methods							
10%	Measurement & Interpretation
20%	Error discussion
10%	Discussion
10%	Ability to reflect
	Remarks:							
		Area	Grade				Overall grade	
Self assesment (to be filled by the student)								
Paedagogical presentation and model building								
Structure and assembly								
Scientific working methods								
Feedback (to be filled by the teacher)								
Paedagogical presentation and model building								
Structure and assembly								
Scientific working methods								

Version 8 (2015-12-01)

Version 8 (2015-12-04)

Fig. 8. Translation of structure of the "Criteria and feedback rubric for lab reports".

CONCEPTS TO INITIALIZE LEARNING ACTIVITIES WITH MODERN MEDIA

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Integrated Use of Scratch and EJS for Promoting Coding Skills of Prospective Primary Teachers

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“Computational thinking” is recognized as an aptitude in children that aids articulation and logical thought. In this context, “coding” is becoming a key skill to be acquired by all young students. It is part of logical reasoning and represents an example of what are now called “21st Century skills”. Here we describe an approach to the development of coding knowledge and skills in prospective teachers with almost no prior exposure. The approach, originally based on the sequential and complementary use of Scratch and EJS software, was tested within a fourth-year course of the degree program for Primary Teacher Preparation at the University of Basilicata (Italy). Preliminary results suggest that the proposed learning sequence can be effective in promoting quick development of the basic knowledge and skills needed to approach coding practice in prospective teachers who were computing-novices. The sequence can serve as an important educational tool for the development of computational thinking in primary teachers.

1 Introduction

At primary school level, computational thinking (CT) is increasingly recognized as a useful ability in helping children to logically articulate their thinking (Wing, 2006). It is an essential skill that allows students to participate effectively in the digital world and prepares them for their future workplace. CT is part of logical reasoning and represents one of the key skills that are now called “21st Century skills” (Trilling and Fadel, 2009; Bellanca and Brandt, 2010); it will be “a fundamental skill used by everyone in the world by the middle of the 21st Century, just like reading, writing, and arithmetic” (Wing, 2015). CT is a skill that can be used in many ways (Fessakis et al., 2013). Notably, from a pedagogical perspective, it promotes the improvement of higher thought processes, which aids the development of problem-solving skills (diSessa, 2001). In fact, when the “solvers”/pupils try ‘teaching’ the computer how to solve a problem, they have the opportunity to articulate their thoughts and to compare the effects of their choices with immediate feedback. This process promotes the development of not only problem-solving skills, but also of metacognitive skills (Clements and Nastasi, 1999; Fessakis et al., 2013).

In this context, coding is increasingly recognized as the framework in which CT can be adequately promoted among young pupils. As a result, many European countries¹ have recently launched national programs to introduce coding in primary school. These coding-centered programs have been developed to provide young learners the basic skills, knowledge and awareness of computing they will need throughout their lives. Notably, students

1 Among others countries, coding has been introduced in Estonia (<http://progetiiger.ee/>), Italy (<http://www.programmailfuturo.it/>) and UK (<http://www.computingschool.org.uk/>).

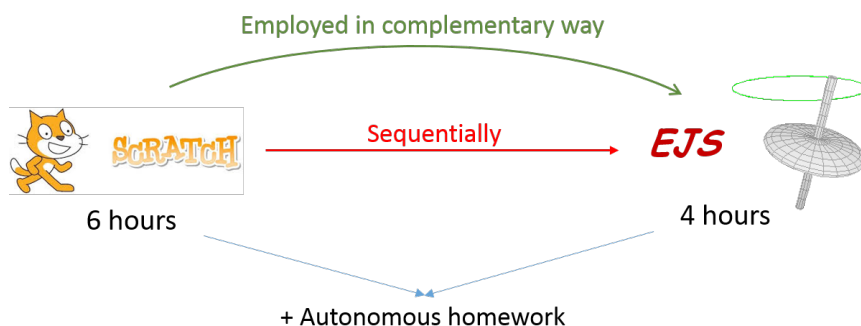


Fig. 1. Structure of the learning sequence tested: two pieces of authoring software, Scratch and EJS, were sequentially employed in a 10+20 hour (in class + at home) activity. The two authoring tools were used in a complementary way, allowing learners (novices in coding) to shift from a visual block-based scripting activity to simple text-based coding practice.

are expected to learn how computers and computer systems work, to design and build simple programs, and to develop their ideas using technology.

The scenario described above makes some basic assumptions about the preparation of primary school teachers and their skills concerning the coding and critical use of multimedia tools. This is crucial, as prospective primary teachers usually do not receive formal instruction in programming languages in high school (at least in Italy). Moreover, instructors usually do not take a specific course on programming languages during university training. As such, promoting the essentials of a programming language among these instructors can be very difficult.

Regarding the educational tools for trainee teachers, there is no doubt that fully visual programming languages (VPLs) are very useful and effective. Furthermore, VPLs are generally well-accepted by novices (Maloney et al., 2008). Nevertheless, learning to code using a VPL presents a shortcoming in the form of “entrapment”, since the exclusive use of a VPL makes it very difficult to learn a textual language thereafter (Hallberg, 2013).

In the above context, we have tried to promote basic coding skills in prospective primary teachers, within the laboratorial activities of the course “Didactics of physics”, that makes extensive use of multimedia representations for teaching kinematics. In particular, we have led non-programmer students to simple textual programming in two steps:

1. They became familiar with the basic concepts of the logic of programming through the use of the software “Scratch” (see paragraph 2.1.1). Scratch is a visual tool designed to enable computing novices without prior programming knowledge to acquire basic coding-related knowledge and skills;
2. In the second step, students were given the opportunity to handle textual code -but only the simplest and most fundamental elements, in order to build familiarity. This was achieved using the “Easy Java/JavaScript Simulation” software – EJS – (see paragraph 2.1.2) which allowed students to edit some code related to the motion of objects without the need for the more complex code that is necessary for the implementation of the Graphical User Interface.

In the rest of the paper, after a short refresher about the employed authoring tools, we describe the experience.

2 Materials and Methods

This research is inspired by the case-study methodology (Yin, 2003). In fact, the work is intended to qualitatively investigate the effectiveness of a new way of introducing coding to prospective teachers in a realistic context, focusing mainly on the perspective of learners.

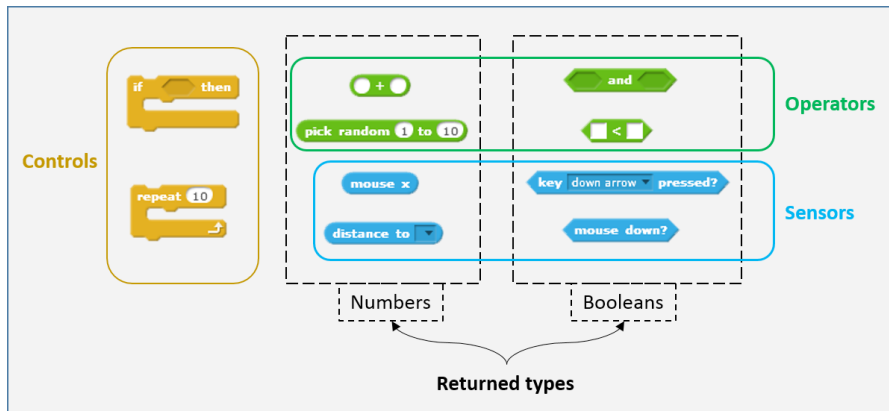


Fig. 2. The function and typology of Scratch's blocks are visually coded by their shapes and colors. For example, Operator blocks are Green, while Sensor blocks are Cyan. For both categories, blocks are shaped according to the types of values they return: the members that output Numbers are oval-shaped, while those that output Booleans are hexagon-shaped. On the other panel, control-oriented structures (e.g. "if-then" and "repeat": left side of the Figure) are orange. Moreover, the structures are C-shaped, suggesting that controlled blocks should be placed inside them. Similarly, the blocks of any kind that have Booleans as arguments have hexagon-shaped voids, indicating a Boolean is required.

In particular, the feasibility and the learning value of the lessons is qualitatively evaluated in a very specific context, partly to look for further research directions.

The introduction of coding to prospective primary teachers has been tested within laboratory activities of the course "Didactics of Physics". This course was given to 4th year students of "Primary Education Sciences" at the University of Basilicata, Italy, during the academic year 2014/2015. The course consisted of 10 hours in the classroom (2 hours a week for 5 weeks) guided by the instructor, and 20 hours of independent activity at home (see Figure 1). Work methodology was strictly practical: each student worked directly with their own laptop, guided by the instructor using the interactive classroom white board.

2.1 The software tools

In this section, we describe Scratch and EJS, the software tools employed in the learning sequence we propose. The underlying principle of each of these tools is the same -the possibility of making "scripts" (see footnote 3) to determine the behavior of objects. This characteristic is implemented differently by each of the two: Scratch employs a fully visual method, while EJS uses a text-based coding template. This difference is exploited by us to promote some simple introductory text-based coding skills in prospective teachers.

2.1.1 Scratch

Scratch (<https://scratch.mit.edu/>) is a fully visual programming environment where the user designs and creates interactive stories, games and animations (Resnick et al., 2009; Maloney et al., 2008). This environment provides a learning approach catered to people who have not previously invested significant thought in programming. Using this tool improves learners' skills in creative thinking and systematic reasoning. Moreover, thanks to its huge online collaborative community, Scratch provides learners/users the possibility to improve their collaborative working skills; it has been called "the YouTube of interactive media" (Resnick et al., 2009).

The syntactical structure of Scratch relies on a collection of visual "programming blocks" that can be fitted together to create programs (Figure 2). Blocks are provided with connectors (analogous to Lego bricks) indicating how they should be put together. Learners can

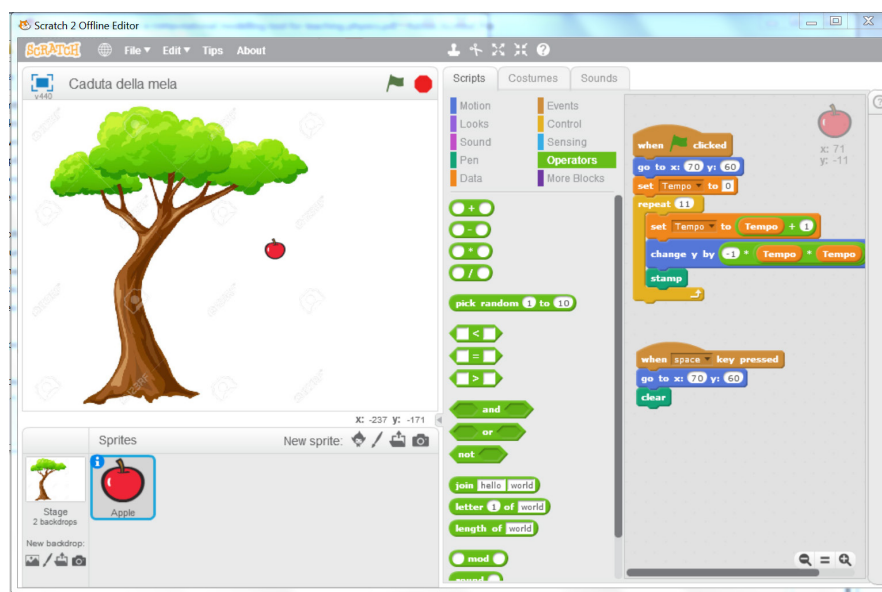


Fig. 3. Structure of Scratch's window. Four main panes are present: i) The main pane (upper left, containing the tree in this figure), is the stage where the animation is shown; ii) The command palette (center of the figure), with tabs and buttons to select categories of available command-blocks; iii) The scripts pane (on the right, with the small apple in the top corner): it shows the sequence of instructions (script) for currently selected item (the apple, in the example); iv) A pane (under the stage pane in the Figure) showing thumbnails of all sprites available in the current project, with the selected item highlighted.

start their programming experience by simply playing with the bricks and exploring different sequences and combinations in putting them together. This can all be accomplished without the trouble of the rigid syntactical rules that characterize most programming languages. In fact, in Scratch syntactic rules are strongly encoded (and their usage forced) by shapes and colors (see Figure 2 for some important examples.)

The Scratch user interface has four main areas that are always visible. As shown in Figure 3, these regions contain: i) the stage where the action happens; ii) the command palette, with tabs and buttons to select categories of available blocks representing commands and syntactical structures; iii) the scripts² for the currently selected item (sprite), i.e. the instruction defining the sprite's behavior during the program's execution; and finally, iv) a pane (under the stage pane in the Figure) showing thumbnails of all sprites available in the current project, with the selected item highlighted.

Scratch is increasingly employed for pedagogically-aimed physics simulations (Lopez and Hernandez, 2015) and the interested reader can find detailed and comprehensive instructions and tutorials in many places (Resnick et al., 2009; Maloney et al., 2010; Learn-Scratch, 2016; Scratch Tutorials, 2016).

² In computer programming, roughly speaking, a "script" is a small program or portion of instructions that is executed by another program, rather than directly by the computer processor, as it is for a "program" in the strict sense. In this connection, the sequence of command-blocks in the "script-pane" of the Scratch's window are "scripts", since they are user-stated instructions aimed to determine a specific behavior of a specific object present in the project (for example, the falling apple in the case shown in Figure 3).

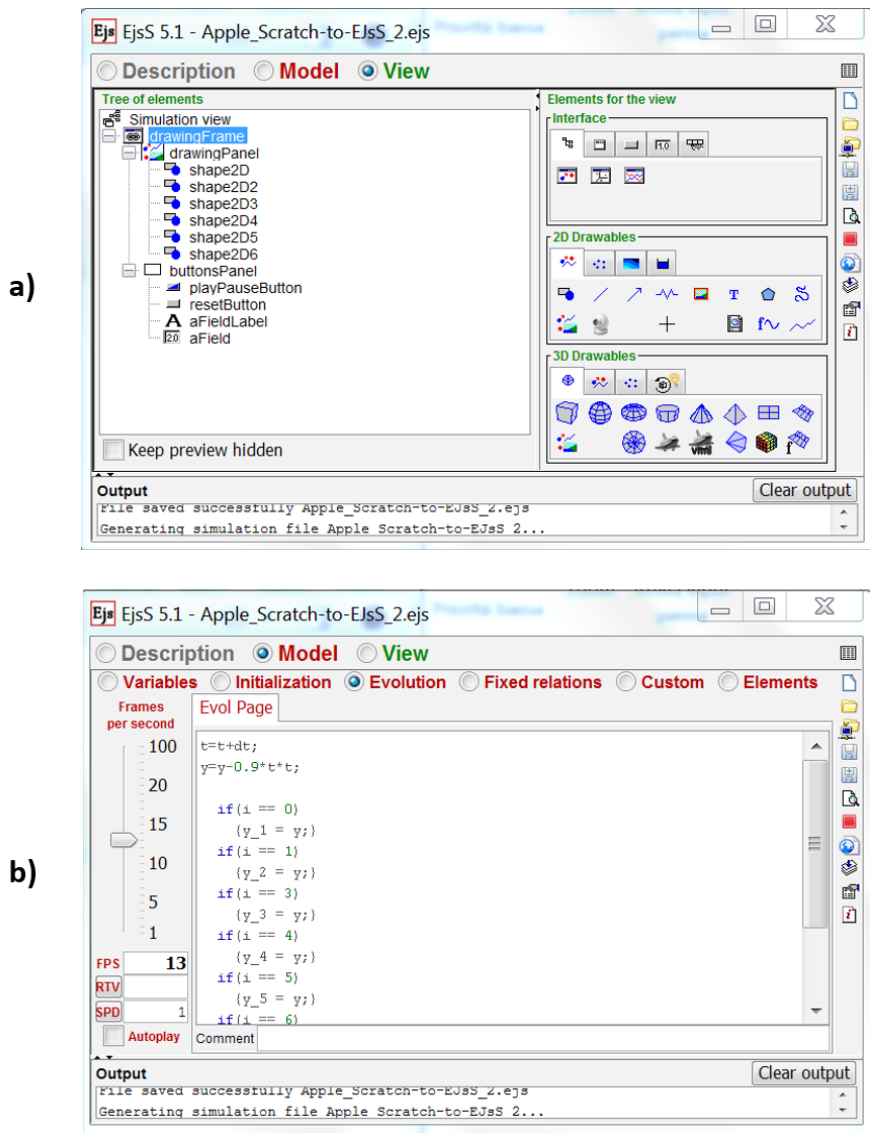


Fig. 4. EJS workspace features three visualization modes, inspired by the Model-Control-View design paradigm. The Figure shows the modes that are used in the proposed learning sequence: The View mode (a) allowing users to build graphical interfaces, and the Model mode (b) that permits customized textual scripting through the “Evolution” sub-pane.

2.1.2 EJS

Easy Java Simulations (EJS, now renamed EJSs, where the new “s” stand for ‘script’, with reference to the scripting language Javascript), is “a free authoring tool written in Java that helps non-programmers create interactive simulations in Java or Javascript.” This is done “... mainly for teaching or learning purposes”, as stated on the web page dedicated to it (<http://www.um.es/fem/EjsWiki/pmwiki.php>). EJSs is an authoring tool very different from Scratch in many respects. EJSs is intended to model physical systems (Esquembre, 2004; Christian

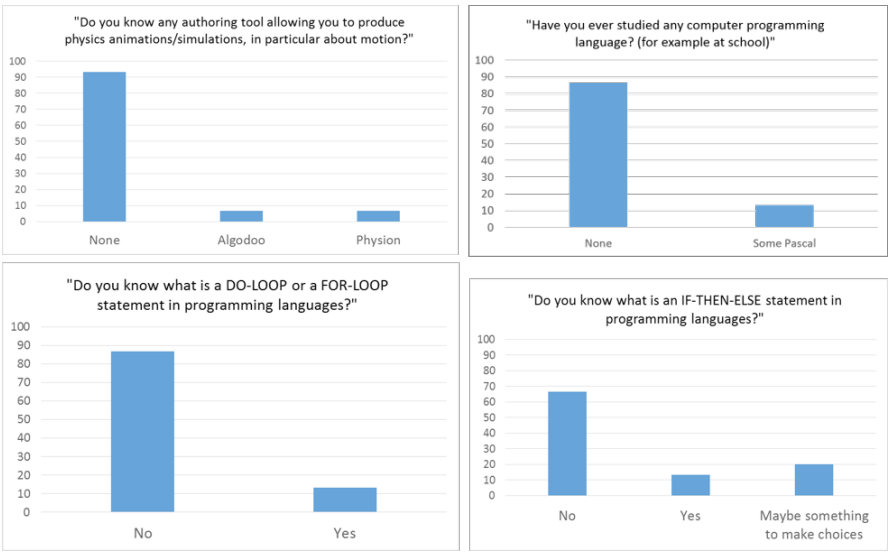


Fig. 5. Taxonomy of students' answers to some typical questions in the pre-test. These results show that students have no prior knowledge of programming languages and little experience with multimedia tools.

and Esquembre, 2007) allowing teachers (and, more generally, users) to create scientific simulations in Java (+ Javascript/HTML5) requiring almost no knowledge of such programming languages. In a sense, it is "a program to build programs". EJS implements a simplified version of the Model-Control-View design paradigm (Esquembre, 2004) and its Graphical User Interface (GUI) features clearly distinct panes reflecting such a paradigm. In fact, the editing section of the GUI allows users to switch between three specialized mode panes: Description, Model and View (Figure 4).

In particular, the View mode (shown in Figure 4.a) allows users to build the Graphical Interface of the simulation they want, by selecting between a series of graphical and interface elements without writing a single line of textual Java code.

Similarly, the Model display-mode (Figure 4.b) features a number of sub-panes (Variables, Initialization, Evolution, etc.) that allows the user to specify the rules governing the behavior of a given element during the simulation. Roughly speaking, the Evolution pane in EJS plays a somewhat similar role to the Script pane of Scratch³ (Figure 3).

2.2 Rationale of the proposal

Our learning sequence on coding has been inspired by a special feature of EJS, not present in Scratch. While the latter is a purely visual programming environment, EJS is a hybrid graphical/textual environment. As such, learners that have previously come into contact with the logic of scripting by using the simpler and fully visual environment of Scratch can capitalize on the coexistence of the two modes (visual and textual) in EJS. In other words, after having implemented a simulation in Scratch, learners can use the visual capabilities of the EJS environment to build the graphical interface of the same simulation without

3 The similarities between the two programs, however, should be taken with caution, as they have very different structures and general purposes. In particular, EJS permits building true stand-alone simulations far more complex than Scratch. On the other hand, Scratch is aimed to learn programming, while EJS allows teachers to produce simulations aimed to learn physics!

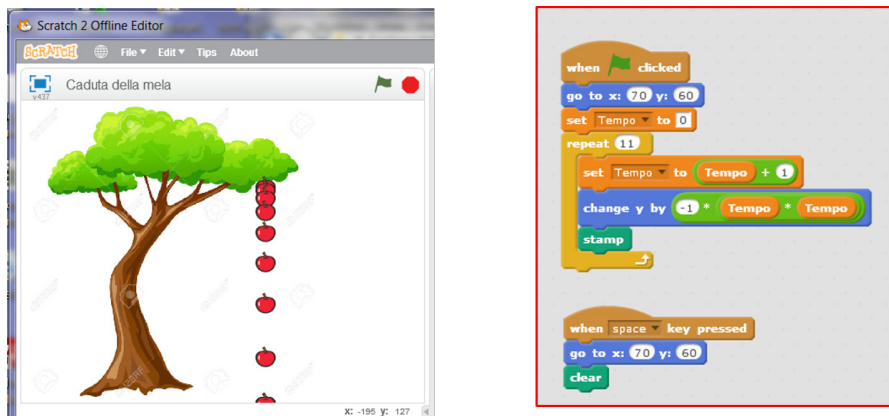


Fig. 6. An example simulation made by students: the fall of an apple from the tree. The left portion of the figure shows the appearance of Scratch's stage after the execution of the apple's script, which is shown on the right.

the need for complex and cumbersome text-based coding skills that are required to build a GUI. Afterwards, learners can focus their attention on a particular object in the simulation already done in Scratch. They can then script the object's behavior by text-based code (using the Model pane of EJS), to get in touch with coding formalism.

2.3 Participants

The experimental group consisted of 30 students voluntarily participating in the trial. Moreover, the activities carried out in this context have not been evaluated using the final examination of the course. Participants were administered a pre-test aimed at investigating their knowledge about coding-related topics. The test showed that participants have essentially no prior knowledge of computer languages, programming logic, or specific multimedia tools. In particular, while about 80% of the students either used or are familiar with physics simulation apps (mainly as high-school students), very few of them are aware of some simple authoring tools. Figure 5 shows the taxonomy of answers to some typical questions in the pre-test.

2.4 Procedure

Students taking the "Didactics of Physics" course were challenged to create a simple kinematics simulation using Scratch. They were then asked to implement the same simulation in EJS. To this end, students used the visual building capabilities of the EJS's View mode to build the GUI of their simulation. After choosing a specific simple object in the simulation, they analyzed its "visual script" in the appropriate Scratch window (Figure 3, right) and then implemented the corresponding "textual script" by using the Model EJS's mode.

There were many different examples chosen by learners. We illustrate a case here which is, in our opinion, particularly significant: the free fall of an apple from a tree (Figure 6). The right portion of Figure 6 shows a block-based visual script for the behavior of the apple in Scratch, while the left portion of the same Figure shows the appearance of the stage after the execution of the script. As one can see, the apple "persists" on the stage during its fall while illustrating the nonlinear increase of distance travelled at each temporal step. This effect is obtained by inserting the Scratch's visual instruction "stamp" in the "repeat" C-shaped loop of the script (the dark green block in Figure 6, right). Thereafter, students tried to build the same simulation in EJS. With this goal, the students translated the "repeat" visual loop of Scratch (Figure 7, top left) into a portion of code (in the EJS

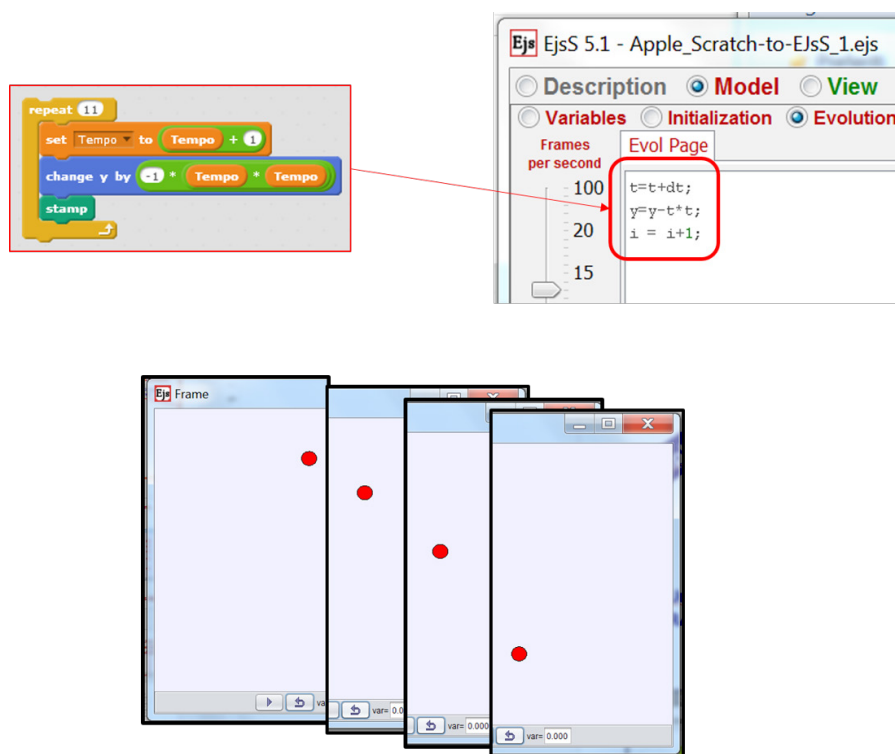


Fig. 7. An example translation of Scratch's visual code (top left) into EJS's textual script (top right), leading to incorrect behavior of the scripted object, the apple (the not-persisting red circle in the bottom portion of the figure).

Model→Evolution pane) consisting of an iteration on the y position of the apple (Figure 7, top right) quadratically increasing it as a function of time. This way of coding led to a non-persisting falling-apple (single the red circle in each screenshot: Figure 7, bottom), differently from the persistent apple (Figure 6, left) obtained with the Scratch code. In other words, at each iteration step, the new position of the apple was shown, while the previous one was deleted; due to the refreshing of the stage at each step of the iteration.

After some discussion, students solved this problem in EJS by using a very different approach to modelling the apple's position. They introduced in the View pane of EJS (Figure 8, left) many instances of the shape representing the apple, instead of a single one. They then scripted the "multi-apple" by using a sequence of "if" statements (Figure 8, right) to draw each instance of the "apple" at the appropriate y-position without erasing it at the next iteration step. This coding solution is neither elegant nor efficient from a professional point of view, but it has been implemented by learners having no prior coding knowledge!

At the end of the semester, during the final exam of the "Didactics of Physics" course, the same initial test (which had been administered about four months prior) was re-administered as a follow-up test to the 30 students who volunteered to participate in the trial. Students were told that the test result would not contribute to their final grades. All thirty students agreed to take the follow-up test, and the results showed that all of them became aware of the main flow-control and looping programming structures that they (almost totally) ignored before the activity.

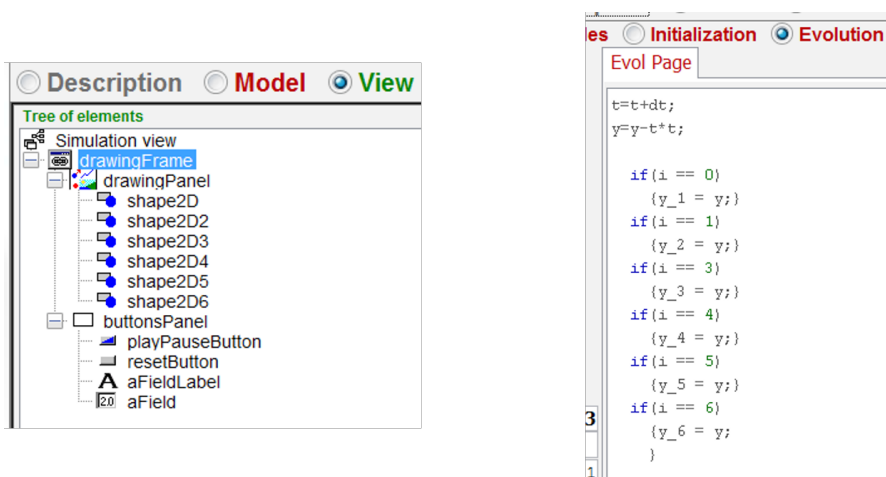


Fig. 8. The coding solution given by learners to the non-persistence problem of the falling apple shown in Figure 7. Many instances of the same shape representing the apple have been introduced (in the View pane, left) governing their behavior with an appropriate script in the Evolution pane (right).

3 Conclusions

In this work, we described the synergetic introduction of two very different authoring tools, “EJS” and “Scratch”. These tools were introduced in a fourth-year course in the degree program for primary teacher preparation at the University of Basilicata (Italy). The goal of this teaching activity was to promote simple coding knowledge and skills in students (prospective teachers) who had almost no prior experience with them. Students taking the “Didactics of Physics” course were challenged to create simple kinematics simulations using Scratch, and to then implement the same simulation in EJS. The core idea of the proposed activity is the “translation” of the visual-block-based scripts (which govern the behavior of objects) of Scratch into the corresponding text portion of code that does the same in EJS. The sequential and synergetic use of the two software tools allows learners to focus their attention on a portion of code devoted to a specific task (the falling of an apple, in the above example) without having to worry about the simulation’s GUI management -which would be absolutely unrealistic. The direct observation of students’ activity, and the analysis of a questionnaire given to them, suggest that the joint use of the above software tools can be effective in allowing computing-novices to quickly develop the basic knowledge and skills needed to approach coding. These skills can become a valuable educational tool for the development of Computational Thinking for prospective teachers. Moreover, observation of the students’ work and the analysis of their outcomes suggest to us that such activities (coupled with the exposure of students to a professional authoring tool such as EJS) may be effective in promoting critical and independent use of multimedia tools in their future teaching activities.

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Movies: A Way to Teach Physics?

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Physics education has always tried to point out the “everyday life” character of physics in various ways. So far, one of the most ubiquitous media, and one with great potential for education, has been widely neglected: feature films. Even though feature films play a huge role in our everyday life they are rarely used to teach physics at schools or universities (Efthimiou, & Llewellyn, 2004). The main aim of this article is to show that the use of movies in physics classes is not only possible but also feasible and productive.

1 Legitimation

Teaching a critical approach to media is one of the general learning objectives in the curricula of many federal states. Although work experience shows that this objective is achieved more often in humanities than in natural sciences, physics can make an important contribution here. Natural sciences not only strive for mere understanding of natural laws, they also aim at their practical application in assessing what is possible in nature and what is not. The use of motion pictures can help to nurture and validate this comprehension. Numerous films try to appear at least as real as possible for the audience (e.g. sci-fi-movies in space), but they contain intentional or unintentional mistakes. Detecting and analyzing such mistakes represents a great opportunity to convey a critical approach to media in teaching physics. Intentional side effects include the consolidation of theoretical knowledge with the chance to apply and connect this knowledge to a popular medium like movies, or more generally, entertainment (Efthimiou, Llewellyn, Maronde & Winningham, 2006). This can be seen as a combination of motivation and fun designed to strengthen the learning effect (Dammachke & Strahl, 2010; Dark, 2005).

2 Scopes

In addition to the media-critical facet, there are further aspects, which not only legitimize but also invite the use of motion picture scenes in physics courses.

Besides the perspective of entertainment, analyzing movie scenes serve the roles of:

- Motivating and sparking interest,
- Providing a diversion from lecture,
- Advertising physics,
- Reducing reservation.

From the point of media literacy the process provides:

- Phenomenological description,
- Approximation methods,
- Critical analysis,
- Review and assessment,
- Natural sciences of imaginary and alternative worlds,
- Stereotypes of sciences and scientists (Weingart & Pansegrau, 2003).

Strahl, A., & Herbst, M. (2016). Movies: A Way to Teach Physics? In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 161–165). Mulhouse: European Physical Society.

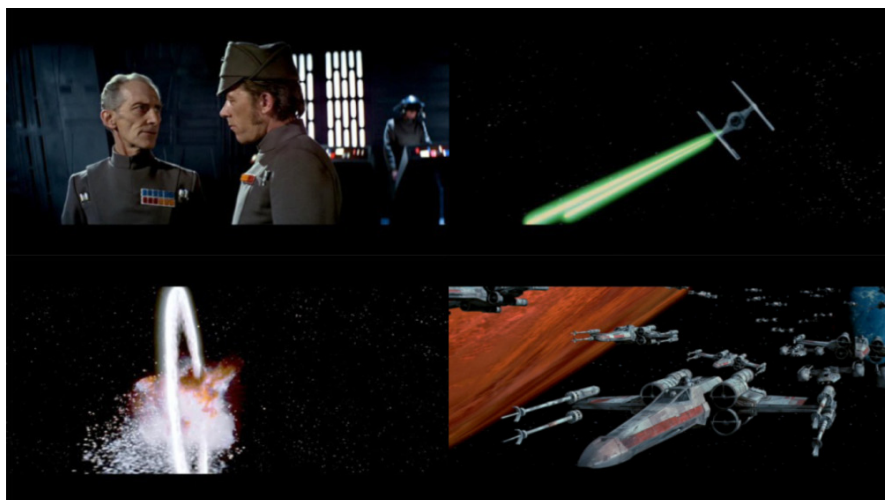


Fig. 1. Star Wars (Star Wars IV, 1977) 3+1 errors.

Regarding “psychological and emotional” aspects, this approach provides:

- Linkage of contents,
- Punctuation (cognitive fixation),
- Experiencing things that one can not or should not do.

Finally, from a “didactics” perspective, this technique facilitates:

- Affective support of learning,
- Formation of a scientific world view.

3 Selected examples of some movie scenes

There is a plethora of movie scenes to be used for teaching physics (Efthimiou & Llewellyn, 2004a & 2004b; Strahl et. al, 2007; Young & Guillot, 2008; Strahl & Bednarik, 2010). However, one must consider whether the scene to be shown should be physically correct or not. In the following, there are two prominent movies showing typically incorrect physics.

3.1 Example 1 – “Star Wars: Episode IV - A New Hope”

The scene used in this film shows the final and decisive space combat. The empire’s Death Star is under attack by the rebels. A bomb is released over a shaft leading to the main power core destroying the Death Star. This scene contains many of the errors that are typical for the representation of space in movies.

1. *Gravitation in spaceships.* Most of the time gravity in spaceships (even the Death Star is classified as a spaceship) seems to be like gravity on earth (Fig. 1, top left). Gravity is caused by mass attraction, whereas spaceships do not have the required mass to elicit self-gravity. One of the first space movies depicting an accurate imitation of gravity (the spaceship is rotating) was “2001: A Space Odyssey”, produced in 1968. Newer movies like “Interstellar” or “The Martian” also exploit this gravity model. However, NASA tests have shown that this method of creating gravity is suboptimal, because people have a feeling of falling down even though they are only resting.
2. *Laser beams in outer space.* Star Wars and many other movies present laser beams as something visible anytime from any position (Fig. 1, top right). First of all, there is generally no matter in space to deflect laser light, which means that you cannot see the path of laser beams; even on earth, laser beams are only visible if they pass through a diffusing medium. Secondly, laser beams in movies are often depicted as pulses, whereby the pulses propagate very slowly which is an outrageous depiction of the speed of light.

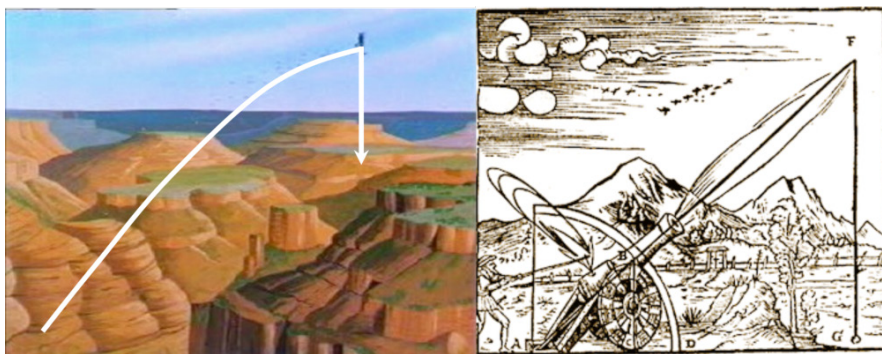


Fig. 2. Wile E. Coyote (Wile E. Coyote and The Road Runner) and the Impetus of the cannonball (Impetus).

3. *Acoustics in outer space* (Fig. 1, bottom left). In many science fiction movies it is possible to hear sounds in outer space (e.g. explosions and even laser beams), but even Hollywood directors should be aware of the fact that the propagation of sound waves requires a medium.
4. *Doppler's principle*. Even though the propagation of sound waves in a vacuum is impossible, the "imaginary" Doppler Effect is displayed correctly (Fig. 1, bottom right). Passing starfighters create the typical pitch change that is associated with cars that pass by an observer with constant speed.

3.2 Example 2 - "Wile E. Coyote and The Road Runner"

The productions of Looney Tunes presenting the stories of Wile E. Coyote and The Road Runner are often very interesting from a physical point of view in that the laws of physics are altered in order to achieve a humorous effect. In this way, Wile E. Coyote is always trying to catch The Road Runner using the most extraordinary ideas a physicist could think of. Most of the time these ideas blow up in his face, perhaps because Wile E. Coyote was not always paying attention in physics class and thus is not considering the laws of physics thoroughly.

1. *The Impetus Theory*. Wile E. Coyote is wearing rocket-propelled roller skates, which allow him to whirl around furiously until he goes up in the air via a rock shaped like a ramp. In the beginning the trajectory looks almost like the parabolic throw, but from the apex it drops down vertically (Fig. 2, left). This trajectory does not correspond to physical laws. This false idea is not completely far-fetched, however, as it corresponds to an idea of movement in ancient times which is even present today as a common students' conception: the Impetus Theory. This theory states that the Impetus of a thrown object, which results from the throw, dissipates during its course of motion. Once the Impetus is exhausted the object drops down vertically. The Impetus theory was also very popular in the early stages of ballistics (Fig. 2, right).
2. *Gravity*. Taking a closer look at Wile E. Coyote shows that from time to time he is able to hang in midair until realizing that he is about to plummet into an abyss. This performance became known in the history of movies as "Road-Runnering" or "a Wile E. Coyote moment". Furthermore, observing nearly every chase sequence in which both are running over the edge of a cliff shows that the Road Runner is not affected by gravity, whereas Wile E. Coyote is subject to normal earth gravity and falls to the ground below. Unfortunately for Wile E. Coyote, the laws of cartoon physics even make it possible for him to overtake rocks (or anvils, cannons, etc.), which fall earlier than he does, so that he ends up being squashed by them (such cartoons would make Galileo turn over in his grave).

Rating	Label colour	Age
0	white	no age restriction
6	yellow	6 and older
12	green	12 and older
16	blue	16 and older
18	red	adults only

Fig. 3. The German motion picture rating system.

4 Terms

A clear policy for the use of movie scenes in school lessons is not given thus far. It should be kept in mind that movies are protected by copyright law like other media. Basically, it can be said that the use of copyright-protected movies is only permitted during class. For this reason, it is crucial that the class is not considered public space and the demonstration pursues a didactic aim (see § 15 para. 3, German Copyright Act). It is paramount to avoid violating the youth media protection. Thus, one must consider the film-rating of the movie with respect to the age of the students. In Germany the acronym is “FSK” (freiwillige Selbstkontrolle [ger], voluntary self-regulation) which classifies movies into five levels (Tab. 1). In addition there are movies that are on the banned list (e.g. *Triumph des Willens* (1935), *Ich klage an*, (1941), *The Evil Dead* (1981), *Terminator* (1984), etc.).

Technical Notes

We would like to point out some practical problems that may arise in the use of movie scenes. There are many ways to show movies—via a digital video or a DVD and a beamer or a TV. First of all, one should select the respective scene in each film in advance to replay it as quickly as possible during the presentation. If using Microsoft PowerPoint or any other presentation tool, it is important to note that the movie scene has to be edited, including appropriate cutting and formatting. WMV turned out to be an advantageous format, especially for operating systems like Windows, as it runs on all versions of Windows Operating System without prior installation of additional codecs. When using Microsoft PowerPoint, one has to consider that movies are not automatically integrated in the presentation, as are images. Therefore, it is necessary that the movie files are stored in the same directory as the presentation file itself. Keep this in mind when transferring data to another computer and make sure that all movie files are copied too.

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**Home Made Spectrophotometer
for a Laboratory Bridging Optics and Modern Physics**
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We present a simple methodology for measuring position and intensity in optic experiments by means of a CCD commercial camera or a cell-phone. The method employs digital photography and image processing techniques that can be used both in introductory physics laboratory and in high school.

With the goal of bridging optics and modern physics, we designed low cost spectrometers based on the use of transmission diffraction gratings suitable for student's lab work. This simple equipment was used to measure the wavelength of visible lines of Balmer series and estimate the value of Rydberg's constant with a relative error of a few tenths of a percent. The method was also employed to evaluate Planck's constant by measuring the wavelength of the light emitted by diodes corresponding to various colours. Finally, it was used to study some peculiar aspects of photoluminescence.

The above experiments have been tested with high school students and with student teachers in a postgraduate course for physics teacher education. Our results indicated that the students were thoroughly satisfied and performed significant analysis on their data.

1 Introduction

The goal of a current research project carried out by the Physics Education Research Groups at the Physics Departments of the Universities of Pavia and Trento (Italy) is to design and test approaches and materials for introducing basic concepts of modern physics in the standard Italian high school curriculum. Our teaching sequence on quantum mechanics based on the sum over path approach was discussed in a different communication (Malgieri et al., 2015b) and some papers (Malgieri et al., 2014, 2015a). In our project, the experimental activities play a significant role. Consequently, in this work, we focus on the design of a laboratory addressing topics from optics and modern physics for student-teachers, in-service Math and Physics teachers, and high school students.

These experimental activities employ image processing techniques and digital photography using a CCD commercial camera or a cell-phone as recently proposed in several papers (Scheeline, 2010; Lorenz, 2014; Kiisk, 2014). In particular, we designed a low cost spectrometer for educational purposes. The spectrometer can be assembled very quickly from simple materials and allows for wavelength and light intensity measurements, in both cases with a good accuracy. This kind of home made spectrophotometer:

- can be employed to evaluate Planck's constant by measuring various wavelengths of light (corresponding to different colours) emitted by diodes.
- permits measurement of the wavelength of visible lines of the Balmer series from atomic spectra as well as estimation of the value of Rydberg's constant (Onorato et al., 2015).

Onorato, P., Malgieri, M., & De Ambrosio, A. (2016). Home Made Spectrophotometer for a Laboratory Bridging Optics and Modern Physics. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 167–176). Mulhouse: European Physical Society.

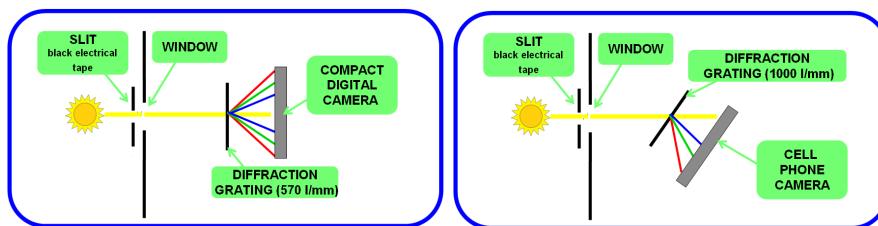


Fig. 1. The spectrometers set up: parallelepiped cardboard box with a hole for the lens of the camera on one side and a narrow window made affecting the cardboard with a cutter on the other side. Two pieces of black electrical tape are placed over the window to form a collimating slit. The light source is placed in front and properly centered with respect to the collimating slit. Two different apparatuses were assembled, the first one, on the left, employs a 570 l/mm transmission grating and a compact photo camera, the second one, on the right, utilizes a 1000 l/mm transmission grating and a cell phone camera.

We tested the use of the spectrometer with groups of high school students and with student teachers in a postgraduate course for physics education. We collected data from the worksheets completed during the experiment, from discussions during and after the experiments, and from the reports the participants prepared afterwards.

2 Equipment and calibration

In Figure 1 we show two different versions of the apparatus. The first one, SC_{570} , on the left, employs a 570 l/mm transmission grating and a compact camera. The second one, SP_{1000} on the right, utilizes a 1000 l/mm transmission grating and a cell phone camera. Both spectrometers are assembled using a black cardboard frame. A narrow window with a width of approximately 2 mm is opened at the distal end of the tube, and a collimating slit is formed by placing two pieces of black electrical tape over the window. The transmission gratings, on the opposite side of the tube, disperse the beam of light entering through the slit into spectral lines with different colours at different angles.

The tube, in combination with the slit, acts to ensure that only approximately collimated light is focused onto the detector by the camera lens. For the calibration measurements, the spectrometer is first pointed at a fluorescent commercial lamp.

The images of the spectra are acquired by a camera, then analysed with version 4.91 of the Tracker video analysis software (2015) which provides direct measurements of RGB channels and of the pixel-by-pixel brightness along a specified line.

The calibration procedure for the spectrophotometers requires two steps: the wavelength calibration (λ -calibration) and the intensity calibration (I-calibration).

2.1 λ -calibration

We use the light provided by a commercial fluorescent lamp. The spectrum shows many peaks distributed over the range of wavelengths of visible light. We acquire pictures of the spectral lines obtained with the two spectrometers and, by means of a PC, accurately measure the positions of their peaks using Tracker. For the reference value of λ corresponding to each peak we use the results of measurements carried out with a high-resolution commercial spectrometer ("Fluorescent lighting spectrum peaks", 2015). In Fig. 2A the positions of the peaks (shown in Fig. 2B) are plotted against their reference wavelengths and the points are shown to be adequately fit by a straight line: $\lambda = 398 + 0.387 x$ for the SP_{1000} , ($\lambda = 398 + 0.556 x$ for the SC_{570}) where λ is the wavelength in nm and x is the pixel number. The uncertainty in the wavelength measurement inferred using this fit is ± 2 nm for the SP_{1000} and ± 3 nm for the SC_{570} . The calibration errors are smaller than the line width of the spectral emission. Thus, a calibration curve was obtained and the points in this instance, which represent peak positions, are adequately fit by straight lines. Wavelength-pixel calibration curves show a coefficient of determination, R^2 of nearly 1.

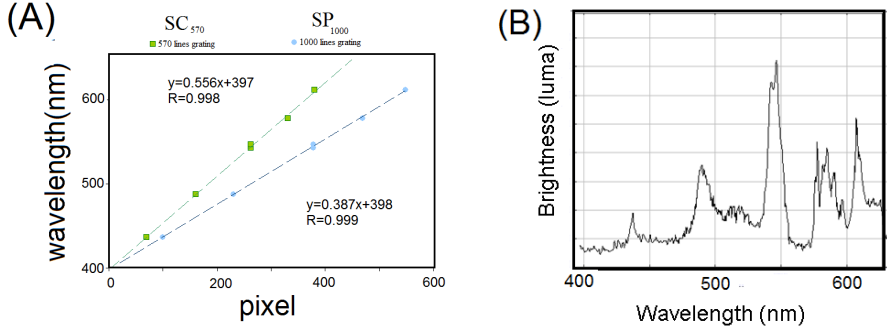


Fig. 2. (A) The wavelength–pixel calibration curves of the spectrometers, based on the fluorescent lamp spectrum. Brightness versus pixel plot is provided by Tracker.

2.2 What are we measuring?

Tracker can measure the brightness along a line in an image using a “line profile” tool. The brightness is measured in luma while the positions are measured in pixels. Luma, a weighted sum of R, G, B primary components represents the brightness in an image and approximates the response of vision to light.

$$Y_{\text{luma}} = 0.2126 R + 0.7152 G + 0.0722 B \quad (1)$$

I-Calibration is required to measure the light intensity, which is calculated from the RGB value in color space (Rossi et al., 2013). To obtain the measure of light intensity from RGB values for a typical gamma-corrected image generated by a camera, we use the formula:

$$Y_{\text{measured}} = 0.2126 R^\gamma + 0.7152 G^\gamma + 0.0722 B^\gamma \quad (2)$$

Where Y is a measure of luminance, which is proportional to emitted light intensity per unit area, and $\gamma = 2.2$ is the factor expressing how the luminance on the screen in a jpeg image depends on the 8-bit RGB color values (ITU-R Recommendation, 2002).

The validity of this formula is controversial and some authors suggest using Raw images. However, not all low-cost cameras can produce images in Raw format. For this reason, we tested the validity of gamma correction with a simple experiment using a variable transmission filter and a commercial camera. We acquired a photo (Jpeg image) of a variable transmission filter, with a linear relationship between the transmission coefficient of the different filters, interposed between a diffused white light source and the camera (Fig. 3A). Then we plotted the successive measured brightness levels against the transmission coefficient according to eq. (1) and eq. (2).

We see in the first plot (Fig. 3B) a marked departure from linearity. However, the same JPEG image analyzed using the gamma correction in eq. (2), shows completely different behaviour, as depicted in Fig. 3C, where linearity is preserved.

2.3 I-Calibration

The value of luminance obtained also depends on the overall response of the apparatus (CCD camera, lenses and so on). As such, we have to evaluate the relative sensitivity (or ‘spectral response’, see Elliott and Mayhew, 1998) of the apparatus by measuring the light spectrum from a known source. We use known data for the spectral irradiance, $I_{s0}(\lambda)$ of a solar disk on Earth’s surface and compare that with our measurements of the solar spectrum, $Y_{s0}(\lambda)$. Thus we experimentally obtain the relative sensitivity, $R(\lambda) = Y_{s0}(\lambda)/I_{s0}(\lambda)$, (reported in Onorato et al., 2014) which converts the measured luminance in the actual intensity, in arbitrary units, for any source ($I(\lambda) = Y(\lambda)/R(\lambda)$).

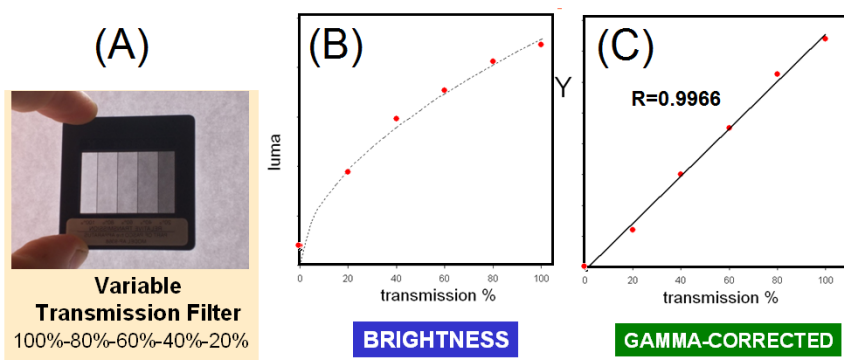


Fig. 3. (A) Jpeg image of light passing through the variable transmission filter. (B) Brightness versus transmission as measured according to eq. (1). (C) Luminance measured using gamma correction.

3 Testing the spectrometer with Student Teachers

In the following we focus on our test of the use of the spectrometer with 20 student teachers (ST) in a postgraduate course on modern physics. ST carried out the laboratory activity as part of a teaching sequence on quantum physics based on Feynman's "sum over paths" approach. The ST carried out the experimental activity in groups with low cost materials and equipments which can be easily found also in a school laboratory. The main purpose of the test with ST was to study the effectiveness of the activities in achieving general laboratory learning goals such as improving technical lab skills, performing error analysis, and communicating results in good scientific language. The effectiveness of the activities in achieving learning goals more strictly related to conceptual learning of modern physics will be studied in future works.

3.1 Measurement of Planck's constant using LEDs

During this activity, ST estimated the ratio h/e using the emission wavelengths and the "turn on" voltages of LEDs of four different colours.

- In the first step, students measured the I - V curve for 4 different LEDs using a PASCO voltage current sensor. Subsequently, the V_F values were found by linearly extrapolating the plots of input current versus applied voltage to zero, as shown in Fig. 4D.
- Students calibrated the spectroscope using a fluorescent bulb to measure the wavelengths of the LEDs.
- Students acquired the images of the spectra for the LEDs and analyzed them using Tracker, thereby measuring the wavelengths for each LED (see Fig 4C).
- Students analyzed data measuring the Planck constant.

Optical emission from LEDs appears when the applied voltage reaches a definite value, V_F , the forward "turn-on" voltage. The energy of emitted photons is hc/λ , where c is the speed of light, and h is Planck's constant. By equating this energy with eV_F , it is possible to determine h/e from the relationship:

$$h/e = V_F \lambda / c \quad (3)$$

Data acquired by students are summarized in tab. 1 and plotted in Fig. 4E.

In these experiments, students obtained a result which is close to the correct value ($4.1 \cdot 10^{-15} \text{ eV}\cdot\text{s}$) to within 7%, or $3.9 \cdot 10^{-15} \text{ eV}\cdot\text{s}$, as reported by other authors using a similar method to measure h in educational laboratories (Nieves et al., 1997, Rute de Amorim, 2014). The wavelengths, λ , were taken at the peaks in the spectra shown in Fig. 4, and the uncertainty in these values is about 20-30 nm.

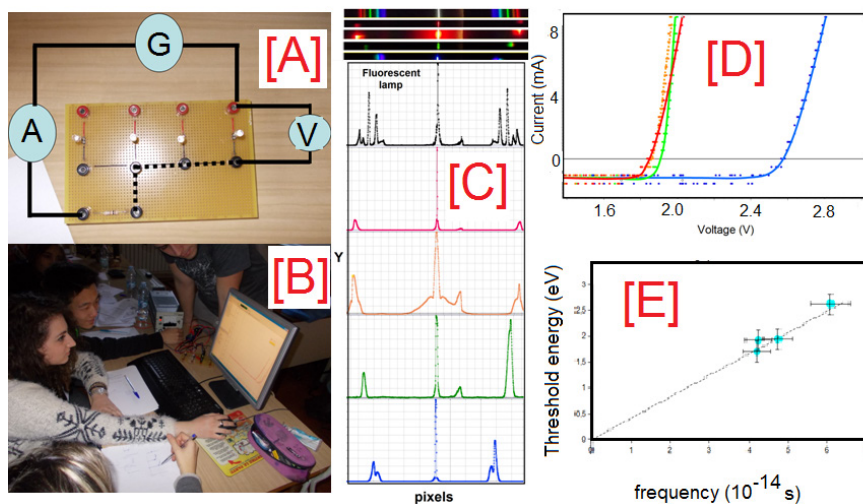


Fig. 4. [A] The basic circuit employed to carry out I - V LED characteristics makes use of 4 LEDs, with an external nominal load resistor of $100\ \Omega$ to prevent too high currents, a standard low-voltage power supply and a current-voltage sensor by PASCO. [B] Students at work in the Lab. [C] Spectra for the LEDs and fluorescent lamp and measurements by Tracker. [D] I - V characteristic of different LEDs. [E] The data and the interpolating straight line.

LED colour	Wavelength (nm)	V_F (Volt)
RED	645 ± 20	1.70 ± 0.02
ORANGE	638 ± 20	1.92 ± 0.02
GREEN	575 ± 20	1.94 ± 0.02
BLUE	486 ± 25	2.62 ± 0.02

Tab. 1. Results of the LED experiment.

3.2 Measurement of the Rydberg constant

Students were required to measure the wavelength of visible lines of Balmer series from the hydrogen atomic spectra and estimate the value of Rydberg's constant. Photos were taken with SP_{1000} while for the measurements needed for calibration the spectrometer was first pointed at a Hg lamp. Spectral data measurements were obtained for 11 trials using a hydrogen discharge tube (right panels of Fig.5). Only three, [B_α (red, $n_i=3$), B_β (cyan, $n_i=4$) and B_γ (blue, $n_i=5$)], of the four Balmer lines were captured by the camera because the fourth line was dim and very close to the violet edge of the visible spectrum.

The values of the Rydberg constant measured by students are reported in the plot shown in Fig. 5 with the error bars. The average value of Rydberg's constant obtained was $R = 1.097 \pm 0.004 \times 10^7\ \text{m}^{-1}$ with an error difference less than 0.06% compared to the accepted value of $1.097\ 373 \times 10^7\ \text{m}^{-1}$. The relative uncertainty on the measurement was less than 0.4%.

4 Analysis of laboratory reports and of discussions

We collected data on the activity and on students' ideas from the worksheets completed during the experimental work, from discussions during and after the experiments, and from the reports prepared by the students afterwards.

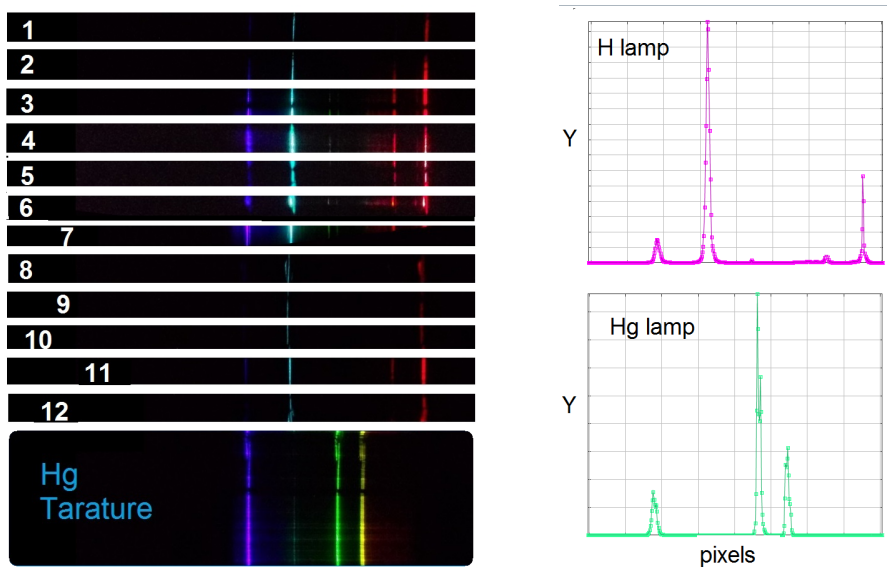


Fig. 5. (A) Spectral lines (red, cyan, and blue) clearly visible in the photos. The spectra are compared with the one of the fluorescent lamps used for calibration. (B) Graphs Y vs. pxl for one of the 12 trials, obtained with Tracker compared with the Hg spectrum.

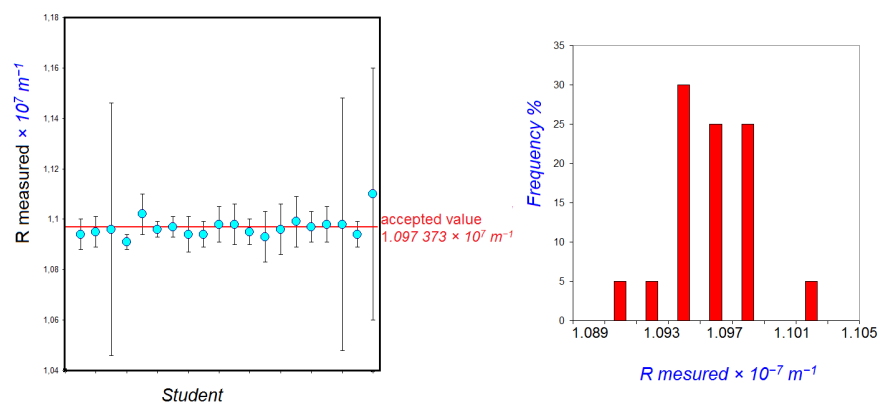


Fig. 6. Values of the Rydberg constant measured by students with the error bars and measurements distribution.

4.1 Evaluation Tools

The students' laboratory reports are evaluated using scoring rubrics based on the items shown in Tab 2. The aim of this analysis is to examine how pre-service physics teachers reason, acquire data and analyze measurement results and how they combine the treatment and presentation of empirical data in their reports.

We use a five level scale to assess each item (4-A Adequate; 3-B nearly adequate; 2-C needs some improvements; 1-D Inadequate; 0-E Missing).

Experimental design:	STs make the aim of the work clear. STs propose a correct experimental design to achieve their goal. STs identify the main theoretical areas. STs clarify the procedure to follow and justify the different steps in their description. STs explain how they will study the interaction of the different variables and if a relationship between the different variables of the system can be established.
Measurements and apparatus	STs are able to use the experimental equipment and correctly perform the measurements. STs are able to correctly calibrate the experimental apparatus. STs have analyzed their results, and explained the limitations of the experimental equipments. STs have proposed how to overcome these limitations.
Data- analysis, uncertainty and result	STs discuss if the data values of the measured magnitude(s) are consistent with expectations. STs calculate the values of the experimental errors. STs discuss what a spurious data point is and how it must be dealt with. STs consider the dependences of the result with respect to the different parameters involved.
Represent information in multiple ways	STs correctly use the written, mathematical and graphical languages. STs switch from one to another correctly. The information contained in graphs, tables and formulas is well understood and explained.
Overall correctness	STs have clearly exposed the most important aspects. STs have used the correct methodology and it has been clearly described.

Tab. 2. Items taken into consideration for the assessment of the lab reports.

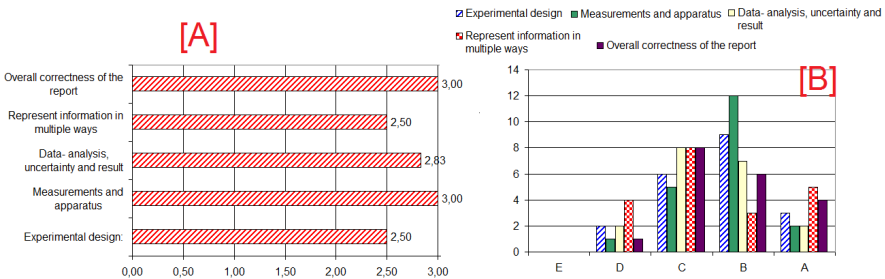


Fig. 7. The average result on each item and the students' distribution in each level.

4.2 Results from Laboratory reports

Results are summarized in Fig.7 where we show the average results on each item and the students' distribution in each level.

More details about the occurrence of some specific elements in the reports are shown in table 3.

4.3 Discussion with student teachers

A positive influence of the activity on the appropriation of experimental methods is clearly demonstrated by the results of our study. We report some of the final comments of STs, in which they highlight the formative role played by these activities and their usefulness in promoting scientific inquiry. They also comment on performing these activities with high school students.

Elements related to the Items taken in account for the assessment of the lab reports	Occurrence in laboratory reports frequency %
Experimental design: Objective definition	67
Measurements and apparatus: wavelength-pixel calibration curve	83
Measurements and apparatus: measurement of the blue line	83
Measurements and apparatus: brightness/intensity curve to obtain the coordinates of the peaks	67
Data- analysis, uncertainty and result wavelength uncertainty	67
Data- analysis, uncertainty and result R uncertainty	83
Data- analysis, uncertainty and result R significant digits	67
Represent information in multiple ways: Plot of the wavelength-pixel calibration curve	50
Represent information in multiple ways: Plot of the intensity -pixel curve	50

Tab. 3. Different elements related to the items of tab 2 and their occurrence in laboratory reports.

About the image analysis and the tools:

"Image analysis can be a useful tool in introducing physics to students who dislike science.... Through the use of the software you can transform any classroom into a lab"

About the inquiry activity:

"The activity is useful because it allows you to experience first hand the difficulties involved in the process of experimental measurement... it provides a good idea of the work of the scientists... it allows you to work effectively on the specific skills of scientific inquiry. "

Or:

"You explore what the typical steps of an experimental investigation are: identification of a goal, ... the need to calibrate an apparatus, ..., the need to analyze the data collected by assigning the values of the measurements as well as their uncertainties... the subsequent discussion of the errors and the comparison of the results obtained in order to assess the compatibility between them and with the known values."

5 Conclusions

A complete analysis of the ST's reports and other data shows that the activities have a significant impact on the self-confidence of students in performing laboratory activities, even concerning subjects regarded as difficult, such as optics. This is a very important result, since a majority of prospective physics teachers in the Italian system have a university degree in mathematics, and if not properly trained, they may be unsure of their lab skills and reluctant to plan experimental activities with students during their whole career.

When tested with high school students in the context of a teaching-learning sequence in introductory quantum physics, the activities also showed effectiveness in raising the students' interest and understanding of the subject

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USING SMARTPHONES AND TABLETS AS EXPERIMENTAL TOOLS

Miguel Á. González and Manuel Á. González

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Physics in Your Pocket: Doing Experiments and Learning With Your Smartphone

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Current smartphones are powerful calculating devices that include a rich set of built-in sensors, which can be used to measure different physical quantities. These capabilities, and the fact that students usually have their smartphones within reach, facilitate the use of mobile devices to teach physics by using smartphones as measurement tools. Experiments that are easy to do and to understand must be designed to facilitate the students' use of smartphones either in laboratory experiments or in their everyday activities. In this work, we show two examples of such experiments using applications developed by our group. A second part of the Instructor's work must be to determine if the use of smartphones improves students' learning and motivation. Some preliminary results of our work with students show that engagement and motivation are improved when the students use their smartphones to learn. Our results on the effects on students' learning are not yet conclusive.

1 Introduction

In recent years, the use of mobile devices in education has increased enormously. In many areas, smartphones are used as knowledge facilitators to ease communication among students or between students and teachers, or to follow or assess the students' progress. For physics students, however, mobile devices have also become useful tools in experimental physics thanks to their rich set of built-in sensors (Kundt & Vogt, 2013). These sensors allow students to use their smartphones as measuring devices in laboratory experiments or during many everyday activities, where the students can strengthen their education by observing nature and contrasting their knowledge or beliefs with their own experimental results.

The use of smartphones as measurement devices in physics experiments with students requires careful attention to ensure positive learning outcomes. Some issues that must be considered include the reliability and accuracy of the smartphones' sensors as well as their adequacy to the experiment in which they will be used. In addition, the precision and accuracy of the applications used to access the sensors data are essential to obtain results that have physical meaning and do not confuse the students (González, González, Martín, Llamas, Martínez, Vegas, Herguedas, & Hernández, 2015). Teachers must also be careful about designing and implementing learning experiments that can be done with smartphones allowing the students to observe the physical phenomena without technical or theoretical difficulties. Finally, the influence of these experiments on different students' education must be carefully analyzed and gains in knowledge, motivation and engagement assessed.

Many recent works have described physics experiments covering many branches of Physics that can be performed using smartphones as experimental tools. Citing only a few of the most representative and interesting published works we have papers on acoustics

González, M. Á., & González, M. Á. (2016). Physics in Your Pocket: Doing Experiments and Learning With Your Smartphone. In L.-J. Thoms & R. Girwidz (Eds.), *Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 179–185). Mulhouse: European Physical Society.

(Kundt, & Vogt, 2013b; Parolin, & Pezzi, 2013; González, & González, 2016), astrophysics (Whiteson, Mulhearn, Shimmmin, Brodie, & Burns, 2014), atmospheric physics (Monteiro, Vogt, Stari, Cabeza, & Martí), atomic physics (Gröber, Molz, & Kuhn, 2014; Kuhn, Molz, Gröber, & Frübis, 2014), magnetism (Silva, 2012), mechanics (Kuhn, & Vogt 2012b; Monteiro, Cabeza, & Martí, 2014; Vogt, & Kuhn, 2014; Monteiro, Cabeza, Martí, Vogt, & Kuhn, 2014; Patrinoopoulos, & Kefalis, 2015; Monteiro, Stari, Cabeza, & Martí, 2015) and optics (Kuhn, & Vogt, 2012a; Yu, Tan, & Cunningham, 2014).

The use of smartphones as measuring devices in the teaching laboratories also permits the substitution of more expensive laboratory devices by smartphones, either by using their internal sensors (Castro-Palacio, Velázquez-Abad, Giménez, & Monsoriu, 2013; Kuhn, & Vogt, 2013b; Sans, Pereira, Gomez-Tejedor, & Monsoriu 2013; Vogt, & Kuhn, 2012) or by using simple and cheap electronics connected to the smartphones' ports (Forinash, & Wisman, 2012a; Forinash, & Wisman, 2012b; Forinash, & Wisman, 2015). These 'low-cost' laboratories would benefit institutions with large numbers of students and small budgets (González, da Silva, Cañedo, Huete, Martínez, Esteban, Manso, Rochadel, & González 2015), but are also an opportunity to design and implement new engaging curricula (Zavrel, & Sharpsteen, 2015).

As a consequence of this expansion of works on physics experiments performed with smartphones, some teachers have begun to wonder about the effects of using smartphones in physics education (Marciel, 2015). One very interesting study that is based on the theoretical framework of context based learning considers the effects of using smartphones on physics students' motivation (Kuhn & Müller, 2015) and shows that the connection of the experimental tool, the smartphones, and tablets, to the students' everyday life has a positive influence on students' motivation. In addition, other recent studies have reported positive outcomes of using smartphones in learning and motivation with temporal stability both for secondary school students (Kuhn & Vogt, 2015) and for university students (Klein, Kuhn, Müller & Gröber, 2015).

2 Doing experiments with smartphones

In this section, we describe some simple experiments that can be done using smartphones. In these experiments, we have used two free Android applications developed by our group: Audia and Sensor Mobile that can be downloaded from the Google app store. Audia (Cañedo, 2014; González, González, Martín, Llamas, Martinez, Vegas, Herguedas & Hernández, 2015) is focused on acoustics measurements and also describes different acoustic phenomena that can be studied with it. This application allows the calibration of the smartphone so that measurements done using different smartphones can be compared. Sensor Mobile (Huete, Esteban, Skouri, da Silva, González, Goudjami, Rochadel, & González, 2015) allows nearly simultaneous access to different sensors of the smartphone, thus recording measurements of different physical quantities in the same experiment.

2.1 Studying properties of materials with the smartphone

The authors Schwarz, Vogt, and Kuhn (2013) propose a method of obtaining the acceleration of gravity, g , by measuring the differences in time of several consecutive bounces. The method assumes that the air drag is negligible and that the loss of mechanical energy is the same in each bounce. As an intermediate step in their calculations, the authors obtain the coefficient of restitution of the ball, k , which establishes the ratio of kinetic energies after and before the bounce, $k = E_{k,a} / E_{k,b} = v_{0,a}^2 / v_{0,b}^2 = h_a / h_b = \Delta t_a / \Delta t_b$. This is later used to calculate g , knowing the initial height of the ball. However, here we propose an alternative to this work and focus on the calculation of the coefficient as the final goal of the experiment. In this way, we can, for example, study the dependence of the coefficient of restitution of different materials with temperature and then apply the smartphone to simple material science experiments.

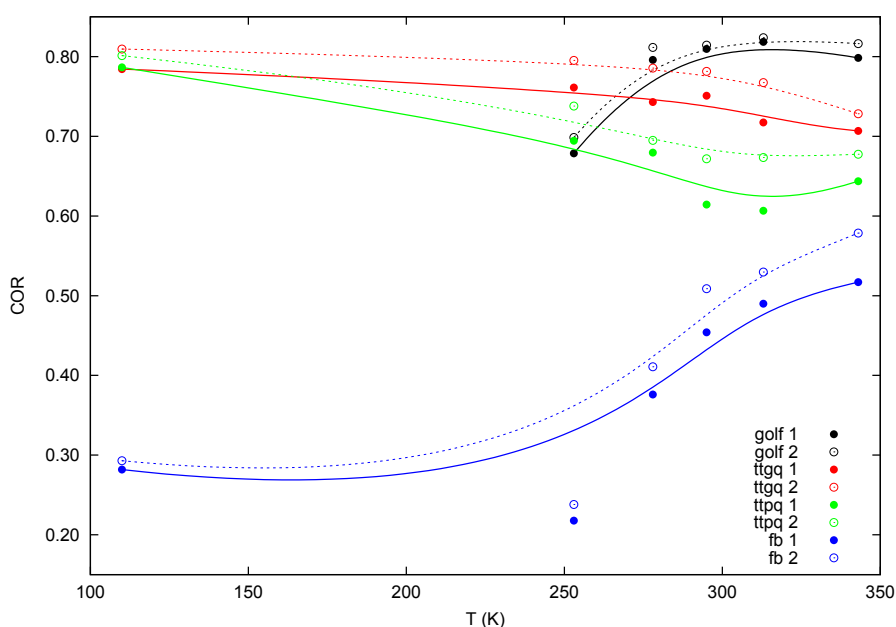


Fig. 1. Dependence of the coefficient of restitution of balls of different materials versus temperature. Two different quality table tennis (ttgq and ttpq), a golf ball (golf) and a foam ball (fb) have been used in the experiment. Results labeled as '1' in the figure correspond to the calculation of the coefficient of restitution using the ratio of times between the second and first bounces, while those labeled as '2' correspond to the calculation using the ratio between the third and second bounces times.

In this experiment, balls of different cheap and easily purchased materials can be used, so that the students can perform the experiment, or part of it, at home. For example, results shown here correspond to different quality golf and table tennis balls as well as a foam ball. In order to measure the effect of temperature, the balls can be submerged in liquids at different temperatures or kept in the freezer. In this experiment, we used liquid N_2 for the lowest temperature, a freezer for temperatures below 273 K and water for temperatures between water freezing and boiling points. For safety reasons, students carrying out the experiment unsupervised should be limited to a safe range of temperatures using only water and a freezer.

Once the calculations of k for different balls and temperatures are done, the students can visualize the different behaviors of the materials, as has been done in Figure 1. In that figure, results for four different balls are compared: a golf ball (golf), a good quality and a poor quality table tennis balls (ttgq and ttpq) and a foam ball (fb). For each ball, two calculations are shown to illustrate the results obtained: in one calculation, the coefficient of restitution was calculated using the ratio of times of the second and first bounces and in the other the ratio of times of the third and second bounces were used. Both calculations were used to analyze the assumptions of Schwarz, Vogt, and Kuhn (2013). As can be seen in that figure, golf data end at about 250 K. At lower temperatures, due to the different behavior of the materials of the ball layers, the ball outer layers tear apart.

2.2 Smartphone physics in everyday life

Different studies have explored the use of smartphones in physics experiments during student activities outside the laboratory. Some of these works have focused on the rich physics that can be observed in amusement (Pendrell, & Rohlén, 2011; Pendrell, 2013; Vieyra,

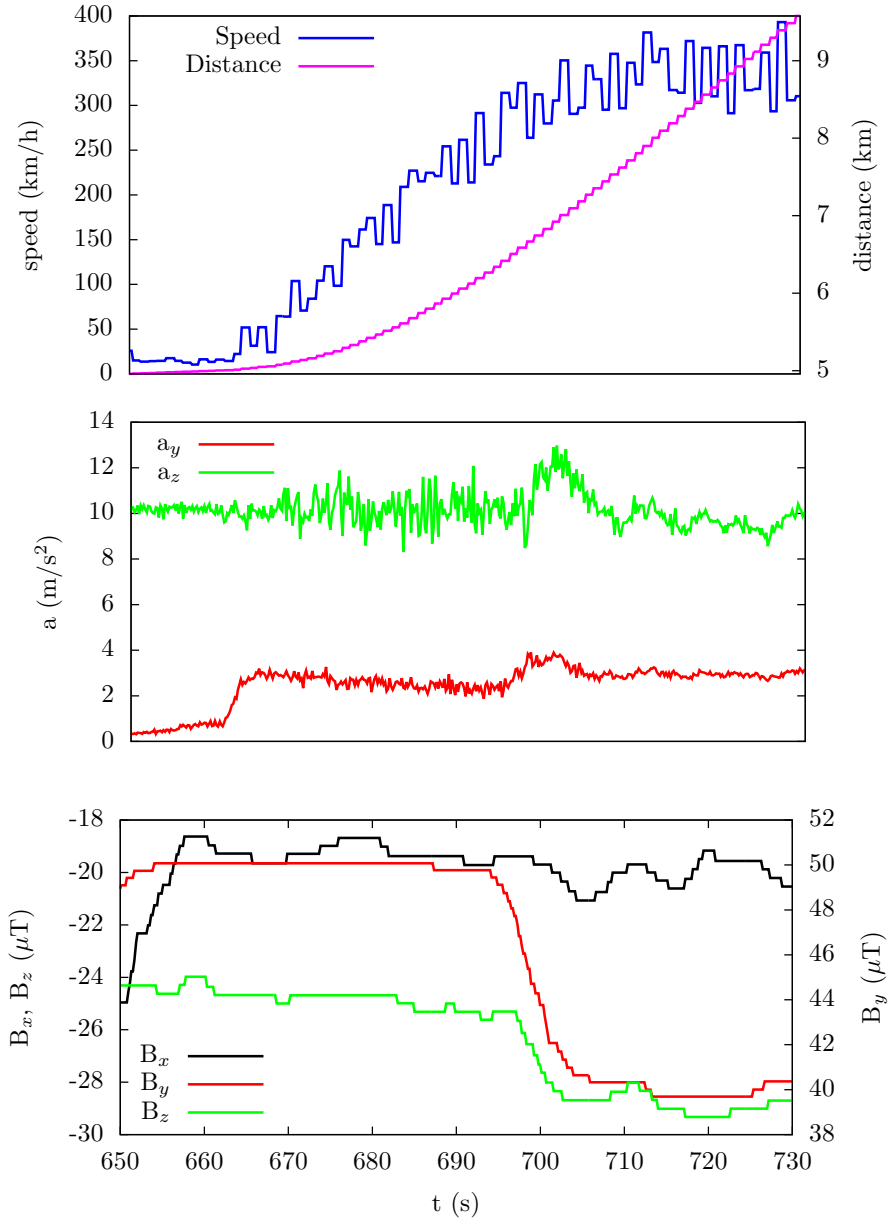


Fig. 2. Simultaneous measurement of acceleration, speed, distance traveled and magnetic field in a plane during take-off, recorded using a Samsung S4 smartphone with the application Sensor Mobile. Students can use measurements like these to understand relationships between different magnitudes and to explain physical phenomena, such as the plane movement along the runway depicted here.

& Vieyra, 2014; Pendrill 2015) or water parks (Cabeza, Rubido, & Martí, 2014). Unfortunately, however, for most student's excursions to amusement parks cannot be considered as *every day activities*. Hence, other works have shown examples of experiments that can be done in more usual situations, such as in an elevator (Kuhn, Vogt, & Müller, 2014), in a merry-go-round (Monteiro, Cabeza, Marti, Vogt, & Kuhn, 2014) or in a car or bicycle ride (González, da Silva, Cañedo, Huete, Martínez, Esteban, Manso, Rochadel, & González, 2015). Here we show measurements taken in a flight take off as an example halfway between the excitement of an amusement park and the reliability of transportation. Figure 2 shows an example of simultaneous measurements of four magnitudes: acceleration, speed, traveled distance and magnetic field, using the Sensor Mobile app while the plane accelerates along the runway and takes off. Off course, security regulations must be followed and the smartphone must be kept in flight mode during this time, however this restriction does not impede measurement with the smartphone's sensors.

Simultaneous measurements allow the students to analyze the relationships between different quantities, for example by comparing the measured speed and traveled distances with those calculated by integration, even using a simple approximate method such as the trapezoidal rule with a spreadsheet, from the recorded acceleration. These measurements also allow the students to analyze data and understand the phenomenon from the graphs, explaining, for example, how the acceleration components change along the runway and in the moment of take off, or the change in the magnetic field components due to the plane pitch at take off.

3 Some works with students

The second part of our research on the use of smartphones in physics education is focused on the analysis of how these tools affect students' progress and motivation. For such a study, learning analytics involving enough students at different levels, capacities and interests are required. Until now, we have done only preliminary works with university and high school students.

The work with university students consisted of supplying the students with mobile apps to complement their physics training. The students who used those applications were surveyed and their grades and engagement compared with those of the non-participants (González, González, Llamas, Martín, Vegas, Martínez, Hernández, & Herguedas 2014). From the survey results, we observed that students saw the use of smartphones as a positive complement to their curriculum. From the analysis of the influence on their grades and motivation, we observed that the use of smartphones increased their interest and engagement, reducing dropouts.

On the other hand, for our preliminary work with high school students we followed a different structure. A few students from two different high schools participated in this work. At the laboratory, they learned how to use the smartphones in simple physics experiments and how to analyze the sensors' data. Then, we propose for them to figure out experiments that could be done 'at home' or during everyday activities. Some of the experiments designed by these students consisted of measuring acceleration and speed in public transport, measuring the resonant sound frequency for different pipes and calculating the speed of sound in air. Other experiments involved measuring friction coefficients between different materials by using inclined planes, or checking the relationship between angular velocity, radius and centripetal acceleration in a carousel (González, González, Martín, Santos, del Pozo, Díez, Prieto, Martínez, Aznar, & de los Mozos 2015). Most of these high school students conceived, performed and analyzed at least two different experiments. Based on this as well as the students' feedback during our interviews with them, our conclusions are that using these devices increases students' interest in experimenting and learning physics, while improving their conceptual understanding. Nevertheless, one must take into account the preliminary character of the experiment, the low population of students involved in it and the qualitative character of the results.

4 Conclusions

The rich capabilities of current smartphones allows for their usage in many physics experiments in the laboratory or outside it. This opens up the possibility of reducing the costs of traditional laboratories by redesigning classical experiments to use smartphones instead of more expensive traditional laboratory material, and even allows students to bring their own devices, which can be very useful under conditions of low budget and large class sizes. Smartphones also allow students to observe and measure many phenomena by themselves. From our work with students, we have noticed that this activity increases their autonomous work and improves their motivation and engagement, reducing dropouts. In this sense, the use of mobile devices opens up the possibility of using learning techniques in which the students play a much more active role. To complete this work, a study on the influence on student's development is required. For that, it will be necessary to analyze academic results of students of different levels and characteristics.

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**INCORPORATING MULTIMEDIA AND ICT IN PHYSICS EDUCATION:
FOCUS ON LEARNING PATHS AND ASSESSMENT**

Onne van Buuren, André Heck and Ton Ellermeijer
Roles and Forms of Assessment of Modelling in Secondary Physics Education
in School Practice.189

Roles and Forms of Assessment of Modelling in Secondary Physics Education in School Practice

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A learning path on modelling and experimentation with ICT has been developed for lower secondary physics education. To monitor student progress on this learning path, several forms of assessment have been used. In this paper, the advantages and disadvantages of several forms of assessment of modelling are discussed. Modelling offers possibilities for self-correction by students, especially if modelling is combined with animation. We recommend to assess computer modelling and ICT-supported experimentation not only with hands-on tasks but also with pencil-and-paper tasks, whether the purpose is formative or summative.

1 Introduction

For both computer modelling and ICT-supported experimentation in physics, many competencies (i.e., skills and knowledge) are required. To name a few: modellers and experimentalists must be able to use software tools, they must be able to analyse and interpret graphs, they must have a sound understanding of the formulas that are involved, they must have sufficient understanding of the physics concepts that are involved, and modellers must understand their modelling approach. Consequently, the cognitive loads of computer modelling and ICT-supported experimentation can be high. The required competencies cannot be mastered in just a few lessons by a novice student; rather, they require a learning path distributed over a long period of time.

Recently, such a learning path on computer modelling, combined with ICT-supported experimentation, has been developed for the Dutch lower secondary curriculum. This learning path is completely integrated into the physics curriculum and has been tested in school (Van Buuren, 2014). One of the goals of this learning path is that students are able to build simple quantitative computer models themselves at the end of their lower secondary physics education. Currently, this learning path is extended into the first year of upper secondary education.

The development of the competencies of students on such a learning path must be monitored carefully by the developers of the learning path and by the teacher. This is necessary to adapt teaching and educational materials to accommodate student difficulties or to take advantage of opportunities for learning. Such adaptations range from small scale —e.g., a discussion between an individual student and the teacher—to large scale changes to the entire curriculum. Ideally, the development of the students' understanding is also monitored by themselves: they must be able to correct themselves. The process of monitoring and adapting or correcting requires formative assessment. Modelling competencies must be assessed for summative reasons as well.

The key question is how modelling competencies can be tested, both for summative and formative purposes, in an effective way in school practice.

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Exams are unequivocally summative tests. In Holland, the examination programme consists of two parts: a nationwide written 'final exam' and a 'school exam'. The school exam is an internal exam, designed by a teacher or a team of teachers at school. It consists of both written tests and more open, practical assignments. These assignments include practical investigations by students. Since 1991, computer modelling has been part of the Dutch secondary physics examination program at pre-university level, but modelling competencies were not tested in the final exam until 2013. As a result, many Dutch physics teachers did not pay much attention to computer modelling. The same holds for publishers of educational materials (Lijnse, 2008). Teachers at about two hundred schools participating in the 'compex exams' were the exception to this trend. At these exams, students' modelling competencies were tested hands-on in experimental computer examinations (Boeijen & Uylings, 2004).

In 2013, new curricula began for the upper levels of Dutch secondary science education. Computer modelling is now part of the programmes for both physics and biology, not only at pre-university level, but also at the havo-level (havo is a five year senior general secondary education program to prepare for higher vocational education). According to Savelsbergh et al. (2008), modelling should mainly be tested in school exams because 'modelling is an iterative process for which creativity, reflection and deliberation are needed'. Hence, modelling should be tested in an open setting; only certain competencies, such as the ability to explore a given model, might also be tested in the nationwide final exams. In accordance with Savelsberg's advice, modelling is now part of the school exams only. The only exception to this is the program for physics at pre-university physics level. At this level, modelling is also assessed in the nationwide final exam, by means of pencil-and-paper tests. A major question is whether modelling should not also be tested in *all* nationwide final exams.

One reason to test modelling competencies in the final exams is that teachers tend to consider topics that are not included in the final exams as less important. A second reason follows from a comparison of modelling with practical investigations by students. Assessment of practical investigation competencies is known to be difficult. It depends on what is considered to be the learning goal, and there are many competencies that have to be dealt with by the students (Gott & Duggan, 2002; Etkina, Karelina, & Ruibal-Villasenor, 2008). Results of different methods of assessment depend strongly on learning styles: some students may perform better with hands-on practical tasks, others with pencil-and-paper tasks (Gott & Duggan, 2002; Roberts & Gott, 2006). Furthermore, the response of a student to a task may be a measure for a variety of competencies and its validity is therefore easily contaminated (cf., Wiliam & Black, 1996; Millar, 2010). For example, in school practice, students' written accounts of an investigation are often used as a surrogate for direct observation of students' actions because direct observation requires too much time. However, students' writings skills do not necessarily correlate with their practical investigation skills (Gott & Duggan, 2002).

Because of the multitude of competencies required for modelling, similar problems can be expected with the assessment of computer modelling. The validity of the assessment may be improved when modelling competencies are assessed not only by means of open investigation in the school exams, but also in a more closed form in written exams. Assessment in a closed form makes it possible to focus on specific competencies, which are difficult to measure in an open setting, because of the contaminating effect of the dependency on other competencies.

The importance of focussing on specific competencies holds even more for formative assessment. Many competencies are essential for computer modelling. Not mastering one of these essential competencies can severely impede students' progress (cf., Van Buuren, 2014). In order to monitor and adjust the development of a single competency of a student, assessment must be focussed on this competency.

In this paper, we present and discuss some of the forms of assessment that we have used while developing our modelling learning path.

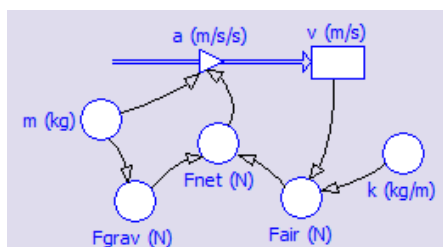


Fig. 1. Graphical model for the velocity v of an object falling through air. The motion of the body is governed by the difference equation $\Delta v = a \cdot \Delta t$, in which the acceleration a is defined as $a = F_{\text{net}}/m$, where the net force F_{net} equals the force of gravity F_{grav} minus the air resistance F_{air} . The air resistance is defined as $F_{\text{air}} = k \cdot v^2$, in which k is a constant. All quantities are depicted by means of icons; arrows indicate the presence of formulas. If necessary, the formulas can be made visible. In Coach 6, this can be done by double-clicking the icons.

2 Method and setting

This paper can be considered a spin-off of an educational design research project. The main purpose of this research project is to establish characteristics of an effective learning path on graphical modelling in lower secondary education and in the first year of upper secondary education. In educational design research, educational materials are designed, tested in the classroom, and redesigned in several iterations (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). The modelling approach we have used is the graphical version of Forrester's system dynamics (Forrester, 1961). We used Coach 6 as an educational tool, because in this computer learning environment modelling can be combined with doing and analysing measurements. Furthermore, in Coach 6, modelling can be combined with animation (Heck, Kedzierska, & Ellermeijer, 2009).

This learning path has been developed for secondary physics education in general, but has been mostly tested in a school for secondary Montessori education. Within the limits imposed by the Dutch government on secondary education, this school strives to work according to the principles of the Italian educator Maria Montessori (1870-1952). A special feature of this school is that students are accustomed to going over their own exercises.

For research purposes, we have made classroom observations, audio-recordings, and computer screen recordings of multiple student groups. The classroom observations often led to dialogue between students and the researcher. These dialogues had the character of small scale in-depth interviews. In addition, written materials and assessments have been collected. Although these data have not been collected with the purpose of studying the effects of assessment methodologies, they did provide us with many indications about these effects. Often, these data were used to further develop questions and tasks that facilitated formative assessment and further tests developments.

3 Graphical modelling

The graphical version of Forrester's system dynamics is often referred to as 'graphical modelling' (Forrester, 1961). In a graphical model, variables and relationships between variables are represented by means of a system of icons in a diagram. Figure 1 shows an example of a graphical model. From a mathematical viewpoint, a graphical model is a system of one-dimensional difference equations and direct relations. Running the computer model boils down to numerical integration of this system.

The direct relations above must be entered by the modeller. An advantage of the diagrams is that they provide a clear overview of the main structure of the model. A disadvantage is that formulas and values are not directly visible. As a result, it takes more time for a teacher to inspect the formulas and values in the model in order to provide feedback.

Explaining graphical modelling in more detail is beyond the scope of this paper. For more information, we refer to another publication (Van Buuren, Heck, and Ellermeijer, 2015).

4 Outline of the modelling learning path

One of the dominant principles of the learning path is that modelling is systematically combined with experimentation and (video-)measurement. The main purpose of the experiments and measurements are to familiarise students with the situations that must be modelled and to provide data that are used for evaluation of the models. On the learning path, the development of each modelling competency is coordinated carefully with the development of other competencies and with the entire curriculum, and vice versa. We did not merely add modelling tasks to the curriculum. Rather, whenever necessary, we adapted the whole curriculum, including the textbook.

The modelling learning path starts in the first year of physics education. In Holland, this is the second year of secondary education (ages 13-14 years). Currently, the learning path is distributed over the first two and a half years of physics education. For a more detailed description of the learning path and the principles that have been used to develop it, please refer to Van Buuren (2014). Here, only a brief outline can be provided.

On the learning path, after only four weeks of physics education, the concept of a model is introduced in a module on geometrical optics. After four months, students start to use simple graphical models in a module on kinematics. In this module, graphs are introduced as well. At the start of the second year, students complete a simple incomplete model by adding a direct relation to the model. During the second year, the main structures of graphical models are introduced. By the end of this year, students create simple models and complete a more complicate model for the first time. In the first month of the next year, students start to build and work with more complicated one-dimensional models in a module on dynamics. To do so, they must, among other things, understand the relationship between the directions and the signs of physical quantities. Also, they learn to use conditional statements (if...then....else-statements).

5 Assessment of modelling

Several forms of assessment have been used to monitor the learning processes. In this paper we distinguish between five dimensions of assessment:

1. monitoring can be done by the teacher or by the student;
2. feedback can be provided almost immediately (fast) or delayed (as is the case with written assessments that have to be reviewed by the teacher);
3. assessment can be done hands-on, with a modelling program, or with a pencil and paper;
4. assessment can be done by means of open, practical tasks or by means of written tests;
5. the assessment can be formative or summative.

In the following subsections, we limit ourselves to the discussion of certain aspects, in particular possibilities for self-correction (dimensions 1 and 2) and the trade-offs between assessment with pencil-and-paper and assessment using ICT (dimensions 3, 4, and 5).

5.1 Possibilities for self-correction

Key feature of formative assessment is feedback. Based on the students' feedback to their instruction, a teacher can adapt their teaching or their educational materials. On the other hand, students can use constructive feedback to correct themselves. This feedback must be constructive and not judgemental, as judgemental feedback can have a negative effect on learning. Ideally, students assess themselves. This was already recognised by Montessori (1912), who developed educational materials that were self-correcting to make children less dependent on the feedback—and judgements—of adults. Recent research confirms the value of self-correction for learning (cf., Lillard, 2007; Black & Harrison, 2010).

Carefully designed modelling tasks offer possibilities for self-correction. Important aspects of modelling are interpretation and, thereafter, evaluation of model output. When students are able to evaluate the output of their models, they may themselves detect their errors and correct their models. In this way, the assessment of the students' modelling

competencies is in the evaluation of the model output. A necessary condition is that students are able to interpret the model output. Therefore, they must (1) understand the way in which the output is represented, and (2) have a reasonable idea what to expect.

Usually, model output is represented by means of tables and graphs. Of these two, graphs provide the better overview. However, a graph is not yet sufficient for novice students to correct themselves, since students can have severe problems understanding and interpreting graphs (cf., Beichner, 1994). Even if students are able to read graphs properly, this is still not sufficient. Experienced physicists recognise important features of graphs, such as parabolic, sinusoidal or exponential shapes, and immediately draw relevant conclusions from these features. As we observed in the classroom, many students cannot yet draw such conclusions, even if they possess the essential knowledge and skills. We observed this phenomenon with first year upper secondary students, who were analysing video-measurements or were modelling a fall under the influence of gravity and air resistance. If the shape of the resulting position-time graph is parabolic, it can be concluded that the net force on the moving object is constant, but many students were not able to draw this conclusion, even if they had the essential knowledge, as demonstrated by their answers to written tests that they had completed earlier. Another example is the effect of an error in the sign of a quantity. This can be considered a minor error; but the consequences for the shape of the graph are immense. As we observed in classroom, this is often not recognised by novice modellers.

If we want to enable self-correction in modelling tasks, we need to do more. One possibility is to use additional representations that are more comprehensible to novices, such as animations. In Coach 6, models can drive animations. An example, taken from the first year of upper secondary physics, is shown in Figure 2. The model in this figure underlies an animation. In this animation, the vectors of the forces are also drawn. The combination of model, animation, and graphs provide students with more comprehensible feedback. In interviews, students stated that they considered these animations very useful for improving their understanding of the varying forces that are involved in this type of movement. Another example of self-correction using a combination of animations and graphs is described by Van Buuren (2014). In this example, we observed how lower secondary students switched between the animation and the graphs in order to correct calculation errors and improve their understanding of the graphs.

Another way to enable self-correction is to prepare students before the start of the modelling task, so that they know what to expect. For this reason, we combine modelling with experimentation. By doing experiments first, students can get acquainted with the behaviour of the real system that must be modelled. Experiments also provide data that can be used as a target result for the model. In Coach, these data can be presented in the form of a background graph.

Target results can also be created by letting students do some calculations beforehand. One way is to do a few iterations of the calculation process manually and create a table. If the output of the model is also presented in a table, students can recognise the values in the table. A more sophisticated way is to let students calculate specific properties that can be expected from the model output. An example is the constant velocity that is reached by an object falling for a long time with air resistance. The value of this velocity can be calculated beforehand.

A special way of creating a target result is by providing students with a hidden correct model which uses the same initial values and constants as the model that students build themselves.

In Coach 6, a 'locked suitcase' can be used to hide this correct model. Such a suitcase is shown in the model in Figure 2.

There is a drawback to the use of target results: they facilitate trial-and-error behaviour. In addition, an incorrect model sometimes can create 'correct' output. For this reason, students must know the learning goals of the task and must be stimulated to reflect on their own work, as was advised by our students in classroom-discussions.

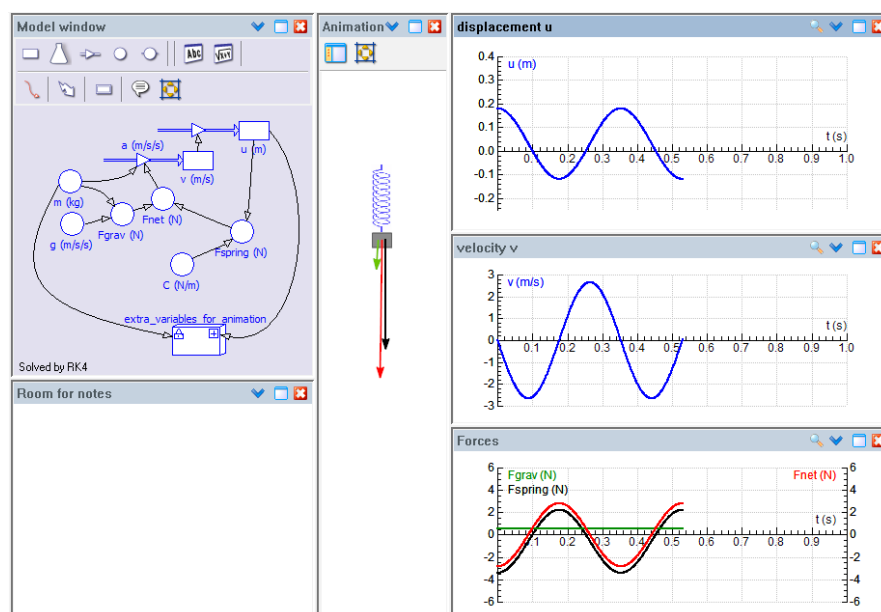


Fig. 2. Shot of part of the screen from a modelling activity in the first year of upper secondary education. A graphical model for a mass attached to a string in the upper left window drives an animation in the window in the middle. The vectors for the force of gravity F_{grav} , the spring tension F_{spring} , and the net force F_{net} are also animated. The graphs in the windows on the right are drawn simultaneously. The 'suitcases' in the model contains variables that are necessary of the animation, but not for the model itself. Such suitcase can also be used to store and hide correct models that students can use to evaluate their own models.

5.2 Hands-on versus pencil and paper

One reason for assessing ICT-related competencies not only with hands-on tasks but also with pencil-and-paper exercises is given in the introduction section of this paper. In a pencil-and-paper exercise, it is easier to focus on a specific competency, without the complications and contaminating effects of other competencies, such as the use of software. This was confirmed by our students; they added to this that computer modelling tasks were often more complex than the tasks they perform without a computer.

However, there are at least four other reasons. The first is a theoretical reason, drawn from the work of the Russian educator Gal'perin. With a concrete object (the computer model) at hand, the actions of a student tend to stay at a concrete level. In order for these actions to become mental, the concrete object must be removed (cf., Haenen, 2001). Thus, after a modelling task, students are given written exercises to stimulate reflection and to support the process of internalisation. Three other reasons were given to us by students on several occasions. First, students tend not to review ICT-activities before a test; rather, they tend to review only the textbook (Van Buuren, 2014). Secondly, it can be cumbersome for students to obtain and start a computer to practice modelling, especially if the learning goal is a single competency. A recent example is the ability to construct conditional statements (if...then...else...-statements). Students explicitly advised us to add pencil-and-paper exercises on this subject.

Thirdly, as students spontaneously explained in interviews, practical work is considered less important by students because it is usually not tested in school in most sciences. According to these students, this argument holds for modelling tasks as well. They advise and even warn us to assess practical work, ICT-competencies, and modelling in regular tests because this stresses their importance. If this is the purpose of a test, written tests are a

less cumbersome alternative for hands-on testing in school.

For summative purposes, we developed both completely written tests and tests that were partly hands-on: students had to use a modelling program on the computer. Comparing the ways students worked with these tests, we occasionally found noticeable differences. In completely written tests, students can easily leave errors in their answers unnoticed. A teacher going over these answers can detect such errors but can also see the other (correct) steps the students took while answering the question. If students used a modelling program, they more easily detect their own errors because they can evaluate their answers by running the model. Consequently, students may correct their errors, but we also observed students who completely ruined or dismissed answers that contained only a minor error after running their model. These students realised that there was a flaw in their model, but sought to correct it the wrong way. This can have a demotivating effect on these students.

6 Conclusions

As we have shown, computer modelling offers possibilities for self-correction by students if the output of the model is represented in a comprehensible way. For this purpose, animations and target results can be useful. The possibility of self-correction can have a demotivating effect in the case of summative tests in which students work with a modelling computer program if they are not able to detect their errors. We recommend assessing computer modelling and ICT-supported experimentation not only using hands-on approaches, but also using pencil-and-paper tasks, whether the purpose is formative or summative, since this makes it possible to focus on single specific competencies. Another recommendation is to assess modelling not only in the internal school exams but also in the nationwide final exams, since this stresses the importance of modelling for both teachers and students.

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