Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning

Edited by Lars-Jochen Thoms and Raimund Girwidz

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Multimedia in Physics Teaching and Learning

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Preface

We are delighted to publish the Proceedings of 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.

Raimund Girwidz

Lars-Jochen Thoms

SIMULATIONS AND VISUAL REPRESENTATIONS IN PHYSICS EDUCATION

Particle Physics:
Three Years After the Discovery of the Higgs

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With the discovery of the Higgs-Boson in 2012, all particles of the standard model of Particle Physics have now been experimentally observed. All particle physics measurements are consistent with predictions; however, we know that the standard model can only be an effective theory. The standard model does not contain gravity, the intrinsic *CP*-violation is not enough to describe the observed matter-antimatter asymmetry in the universe, and the model doesn't contain a particle candidate for Dark Matter. I will briefly review the status of the standard model of particle physics and its key measurements, including the discovery of the Higgs-Boson at CERN. The open questions of modern particle physics will be presented and theoretical scenarios, which could solve these problems, will be discussed. The experimental program will also be summarized, including the latest results from the restart of the LHC in 2015. Education and outreach is an important function of the international particle physics community. A variety of tools are available to explain the main concepts of particle physics to students and to the general public and, even more important, give them an idea of how research in this field is performed. Some of these tools and so-called hands-on exercises for students will be presented.

1 Introduction

Where do we come from? What does the future of the universe looks like? What is nature made of? Mankind has always wondered about these types of fundamental questions. The effort to find answers to these questions is part of our culture and often motivates young people to take up physics and science in general.

Elementary particle physics is one possible avenue to approach these fundamental questions. Deeper insight is gained by subdividing matter into the smallest objects possible. The ancient Greeks already followed this approach and called objects, which cannot be further subdivided 'ἄτομος', a word that inspired the name for atoms. Today we are not only looking at the fundamental objects of matter themselves -we are also trying to understand how these objects interact with each other – via the fundamental forces of nature. While more than 2000 years ago, these questions were raised by philosophers – as pure *'Gedankenexperimente'* – modern particle physics tries to provide a deeper understanding of this problem by performing experiments. Improved technologies lead to deeper insight into matter and currently the standard model of Particle Physics gives the best available description the building blocks which make up the world around us.

2 The standard model of Particle Physics

The standard model of Particle Physics consists of different categories of fundamental particles (e.g., see Braibant, Giacomelli & Spurio, 2012). The first type of particles describes

Schieck, J. (2016). Particle Physics: Three Years After the Discovery of the Higgs. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 13–24). European Physical Society.

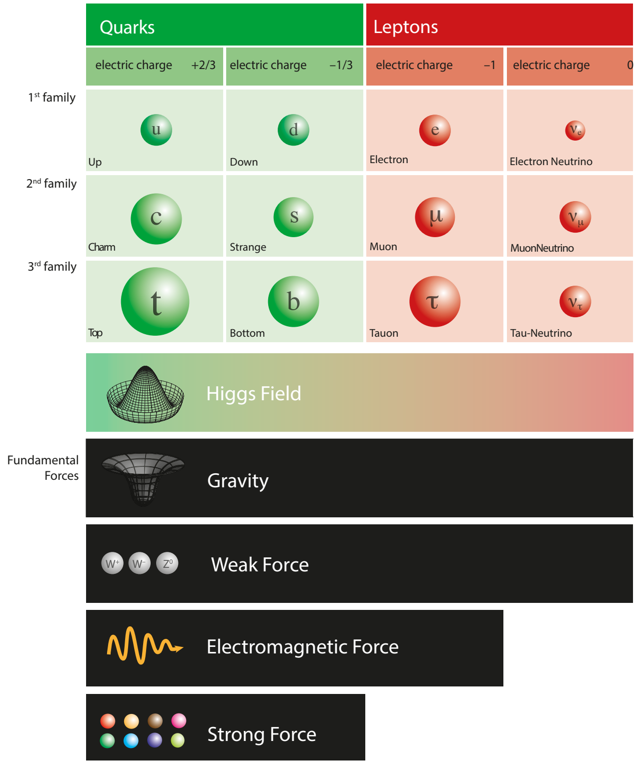

Fig. 1. The fundamental building blocks of matter and the particles responsible for the interaction between these fundamental building blocks are summarized in the standard model of particle Physics (© 2013 Excellence Cluster Universe).

matter and consists of so-called quarks and leptons, which appear in three different instances or generations. Quarks are the constituents of protons and neutrons, and together with an electron (a lepton) form atoms. These fundamental particles interact with each other by exchanging another type of particle – the so-called gauge bosons. These gauge bosons, the second category of fundamental particles, describe three of the four known fundamental forces (see Glashow, 1961; Weinberg, 1967). Gravity is not part of the standard model (SM). The strong force, weak force, and electromagnetic force are described by the exchange of gluons, W- and Z-bosons, and photons respectively. Not every gauge boson can couple to every matter particle, however, and for this reason particles interact differently. The coupling and its strength are described by the charge of the particle. The electric charge is a well-known example. Particles with electric charge interact via the electromagnetic force; neutral particles do not. Similarly, the strength of the weak and strong coupling is described by a weak and strong charge respectively. Quarks carry a weak and a strong electromagnetic charge and therefore take part in all three interactions. Charged leptons do not carry a strong charge and take part only in the weak and the electromagnetic interaction. Neutral leptons, the neutrinos, interact only weakly and are for this reason very hard to observe. Some of the gauge bosons carry a charge themselves and couple to each other. The fundamental building blocks of the SM, quarks, leptons and the gauge bosons, are summarized in Figure 1.

The size of the force a particle experiences also depends on the scale at which we observe the interaction. Our daily experience from electromagnetism shows this effect and the $1/r^2$–dependence of the electromagnetic force is an example of this behavior at the

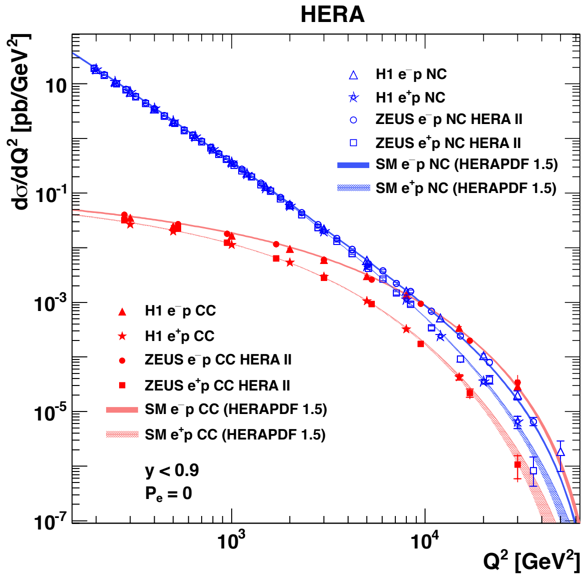

Fig. 2. Probability for a reaction ($d\sigma/dQ^2$) as a function of the exchanged energy (Q^2) or scale. For low energies the difference between the electromagnetic force (blue) and the weak force (red) is significant. For higher energies the difference vanishes and the forces can be described in a unified way (© DESY Hamburg).

classical scale. The force carriers of the strong interaction, the gluons, carry a strong charge themselves, and interact with each other. This self-interaction leads to self-screening effects and for this reason the strong force decreases with decreasing distance – the opposite behavior of the electromagnetic force. The strong force is responsible for the confinement of quarks in protons and neutrons. At a certain energy scale, these forces might unify to a single force. An example is the unification of the electromagnetic and the weak force to the so-called electroweak force. At this scale the sizes of the interactions of both forces are similar and the forces can be considered unified. Physicists suspect that at higher energies the remaining forces will also be unified. The dependence of interaction strength for the electromagnetic and the weak force between elementary particles on energy or distance can be experimentally observed and is depicted in Figure 2. At a certain energy scale the electromagnetic and the weak force is of the same order of magnitude and both forces can be theoretically described in a unified way. A long-standing problem of the Standard Model has been the experimental evidence to support a coherent description of the mass of the fundamental particles. Different groups suggested a solution to this problem by introducing a new scalar field, the Higgs-field, with its symmetry being explicitly broken (see Englert & Brout, 1964; Guralnik, Hagen & Kibble, 1964; Higgs, 1964; Higgs, 1966; Kibble, 1967). Finally, in 2012, almost fifty years after the development of this theoretical idea, particle physics experiments at the Large Hadron Collider (LHC) at CERN (see Evans & Bryant, 2008) were able to detect the Higgs-boson – an excitation of the Higgs-field (see Aad et al., 2012; Chatrchyan et al., 2012). This discovery was a big step towards a deeper understanding of the fundamental building blocks of our universe. Does the Higgs-field explain the origin of all visible mass? No! The mass of the constituents of the proton and the neutron, up-quarks and down-quarks provide only a small fraction of the total mass of the nucleon. Dynamic processes originating from the strong force, and mediated by gluons, create the majority of the mass.

Fig. 3. A look into the LHC tunnel at CERN with a 3D cut of a LHC dipole magnet. The two red lines indicate the expected trajectory of the protons within the two beam pipes, indicated by the yellow color (LHC © 2014-2016 CERN).

3 The experimental road towards the Standard Model of Particle Physics

Particle physics tries to identify the fundamental buildings blocks of matter and the interaction between them. Experimentally these fundamental building blocks are studied by using high energy particle beams provided by large particle accelerators. This experimental technique can be easily understood by comparing this approach with the way we observe objects with our eyes. Our eye observes objects by detecting light scattered off of the objects we observe. In particle physics the same approach is used. Instead of light being scattered off of the object, high energy particles are used as a testing probe and are scattered off of the object under investigation. The scattered high energy particle is then observed by the detector. From the scattering process we can draw conclusions about the object under investigation. In the case of observing objects with a microscope using the scattered light, resolution is limited by the wavelength of the light. In quantum theory each particle can be characterized as a particle or a wave, with the wave being described by the so-called de-Broglie wavelength. The de-Broglie wavelength of a particle λ is related to its energy by the formula $E = hc/\lambda$, where E is the energy of the particle, h is Planck's constant and c is the speed of light. Similar to the observation of objects with a microscope the resolution is limited by the wavelength of the testing probe. The de-Broglie wavelength is inversely proportional to the energy of the testing probe and for this reason very highly energetic particles are required as testing probes to study the fundamental building blocks of matter. More highly energetic particles allow the necessary access to smaller length scales. In the famous Rutherford experiment, α-particles from radioactive decay were used to probe atoms and to discover the nucleus as one of their constituents. Later, a similar experiment using electrons from particle accelerators was performed to probe the composition of the proton (Breidenbach et al., 1969). With state-of-the-art accelerators, resolution up to 10^{-18} m can be obtained. Currently, quarks and electrons are considered point-like without any further substructure. Future particle accelerators providing even higher energies will test this assumption at even smaller length scales.

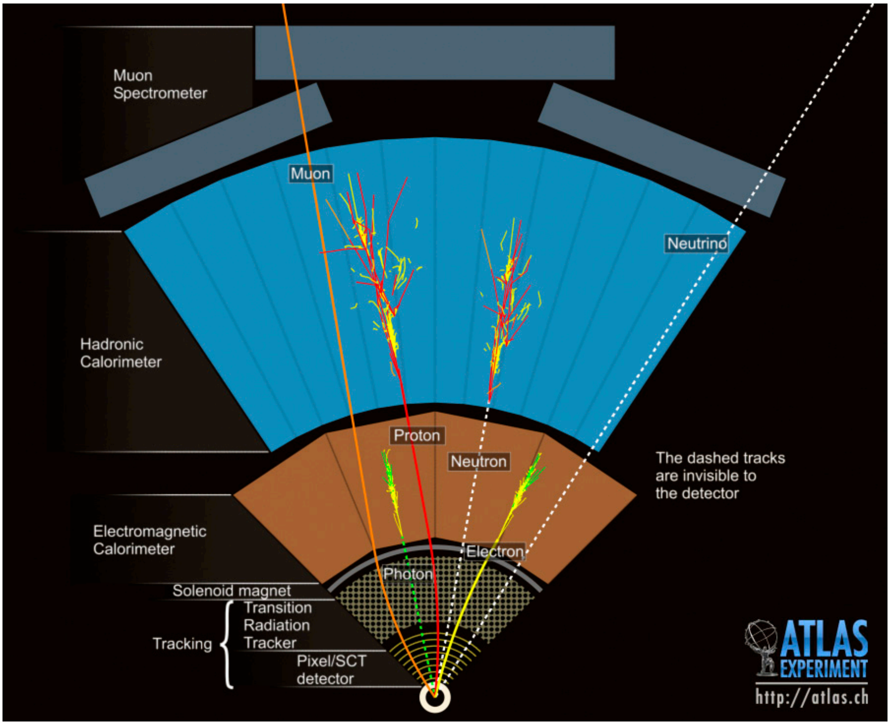

Fig. 4. Sketch of an event cross-section of a simulated event generated in the ATLAS Detector at the LHC. Different types of particles (indicated by colored trajectories) leave different signals in the detector. The momentum of charged particles is reconstructed by determining the bending radius of the trajectory in the magnetic field (inside the solenoid magnet) (© ATLAS 2008 CERN).

Besides the fact that high energetic particles can act as a testing probe to resolve substructures with high resolution, highly energetic particles can also provide access to new mass scales. Special relativity relates energy and mass via the famous formula $E=mc^2$, meaning energy and mass can be transformed into each other. In a particle collision energy and momentum are conserved and applying the formula $E=mc^2$ to the collision implies that the energy of the initial particles can be transformed into mass. As a result, new particles with masses greater than the initial colliding particle, can be created. This fact was e.g. used for the production and discovery of the Higgs particle. Two protons are accelerated and in a head-on collision the kinetic energy is transformed into mass and a Higgs particle is created.

Particle accelerators are the key tool necessary for conducting these studies, and for exploring even smaller length scales or creating particles with high masses. The most powerful accelerator today is the Large Hadron Collider (LHC) currently in operation at CERN[1] in Switzerland. At the LHC, groups of protons are accelerated in a circular collider and are brought to head-on collision. Each group consists of about 10^{11} protons, which are accelerated to an energy of 6.5 TeV for each proton, corresponding to a velocity of 99.9999997% of the speed of light. For the head-on collision, the two proton groups are focused on an area of about 100 μm^2. Figure 3 shows a glimpse into the LHC tunnel with dipole magnets being installed. The dipole magnets are responsible for keeping the protons on their circular trajectory.

1 http://www.cern.ch

Around the collision point, detectors are installed to record the trajectory of the created particles (see The ATLAS Collaboration et al., 2008; The CMS Collaboration et al., 2008). Some of the particles decay more or less instantaneously and only the decay products can be observed. The Higgs particle, for example, decays in about 2.6% of all cases instantaneously into two Z^0-bosons, which can further decay into two pairs of muons. Thus, in the detector the Higgs is being treated as four individual muon tracks and the Higgs is identified by its invariant mass, calculated from the relativistic four- vectors of the decay products. To fully characterize a particle, the energy, momentum, lifetime and charge has to be measured. These quantities cannot be determined with a single detector type only and typically several sub-detectors with different reconstruction tasks are combined. Figure 4 illustrates the operation mode of such a detector. In order to avoid missing any particle, the detector provides almost 4π of solid angular coverage around the interaction point.

4 The next steps and outstanding questions

With the discovery of the Higgs-Boson in 2012 at the LHC, all particles of the standard model of particle physics have been verified experimentally. All particle physics measurements are in excellent agreement with the standard model. Only the fact that neutrinos have non-zero mass is not accommodated in the standard model initially proposed. However, adding minor modifications to the theory can solve this problem. What's next? Are we done with particle physics? Of course not! Besides not having any idea how to tackle very fundamental questions like *"why do we have exactly three generations of particle"* more particle-physics specific questions arise. Most of these questions are motivated by astrophysical observation. The most obvious question is related to gravity and why gravity is the only one of the four known fundamental forces that cannot be described coherently by quantum field theory and is not part of the standard model of Particle Physics. Next, there are questions like *"why is there more matter than antimatter?"*, *"what is dark matter made of?"* or *"what is dark energy?".* None of these questions can be answered with the standard model of Particle Physics but we assume that a more fundamental theory beyond the standard model exists, which can give an answer to these questions. Based on historical observation, particle physicists believe that new undiscovered particles and new forces will explain the outstanding mysteries. Figure 5 shows the development of the number of particles being considered fundamental as a function of time. Introducing new particles accommodates more experimental observations and at a certain point new fundamental concepts allow the description of physics by a more comprehensive theory.

A very good candidate for such a comprehensive theory is called Supersymmetry. This theory is a model relating matter and forces that doubles the particle spectrum, similar to doubling the number of particles by introducing anti-particles. Introducing a new type of symmetry is the basis of this new theory. Recent measurement at LHC could exclude simple realizations of this model. However, the parameter space of this model is large and although Supersymmetry might yet be realized, it has not yet been experimentally verified. In 2015 the LHC re-started after a two year long extensive upgrade program. The center-of-mass energy has been almost doubled from 8 TeV to 13 TeV, opening the possibility of testing new unexplored regimes of size and mass.

5 Multimedia in Particle Physics

Over the last two decades, outreach and education has become a natural part of the work of almost every particle physicist. In order to obtain political and financial support for future particle physics projects, scientists have to share their excitement and explain the motivation for their research to society. Remarkably, in recent years major particle physics conferences have even offered a dedicated forum on education and outreach. Besides this, the types of questions related to fundamental science that this field explores often provide a natural entry point for high school students to natural sciences.

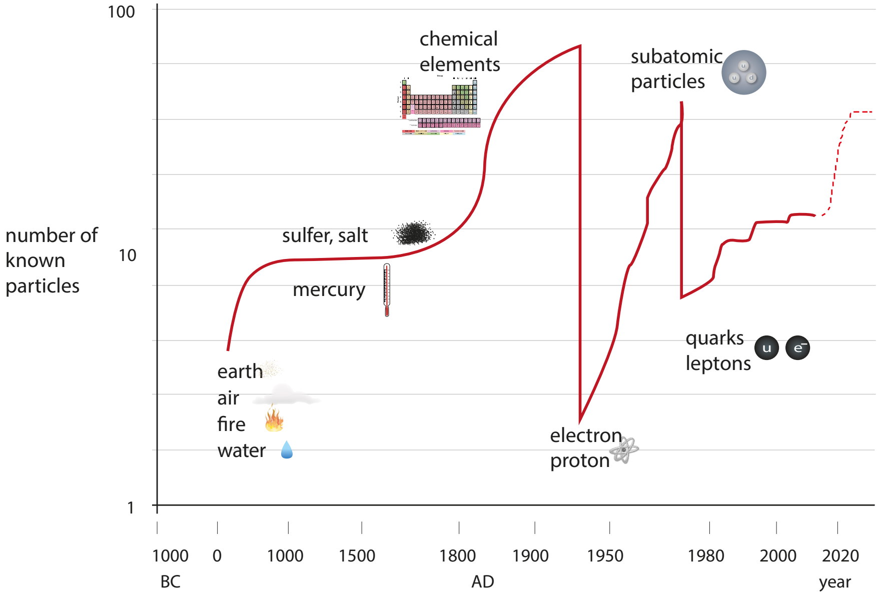

Fig. 5. Time development of the number fundamental particle from the ancient world until today (© 2013 Excellence Cluster Universe).

I would like to discuss several forms of multimedia that have potential for education and outreach purposes in particle physics. I subdivide them into three different use-cases

- *Physics case*: Multimedia for explaining and aiding the understanding of fundamental physics questions
- *Technology*: Explain the methods and the technical realization behind how particle physics experiments work
- *Get involved*: Prepare particle physics experimental data to allow students and the general public to participate in science

Below I will briefly present several multimedia particle physics use cases. The main focus will be on the third use-case – *get involved*.

5.1 Sketching Math – Feynman Diagrams

Feynman diagrams are simple "multimedia tools" to explain particle physics processes. The standard model of particle physics uses quantum field theory to describe and predict physics processes. The mathematical language is exact, however the underlying physics often cannot be seen easily, even for very simple questions. In order to find a simple language to describe the physics behind the math, Richard Feynman introduced a graphical language to describe the physics. A one-to-one correspondence between the mathematical terms and the graphical representation is introduced, which facilitates understanding of the physics process without deeper knowledge of the underlying math. Figure 2 shows a Feynman diagram of the decay of a K_L meson in a neutral pion and a pair of neutrinos. The corresponding mathematical expression would be very complicated and hard to understand, while the sketch with the different transitions can be understood much more easily.

Several interactive multimedia tools providing additional help toward understanding physics questions can be found at the WWW-page of the International Particle Physics Outreach Group[2].

2 http://ippog.web.cern.ch/resources

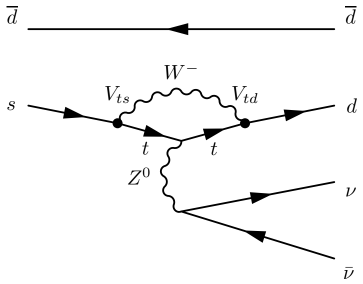

Fig. 6. Feynman Diagram of the decay of a K_L meson ($s,\bar{d}$) into a π^0 ($d,\bar{d}$) and pair of neutrinos.

5.2 Detector physics – how do I see a particle

Experimental particle physics is an ambitious technological enterprise, but a necessary tool towards a better understanding of nature. Understanding physics requires an understanding of experimental tools to a certain extent. These tools are quite often dedicated tools developed specifically for special particle physics use case. The detection and reconstruction of particles is a crucial part of experimental particle physics. Animated WWW-pages can help the public understand the working principle of such a detector. Based on a simple illustration such as what is shown in Figure 4, a WWW-page permits interaction with the user[3]. The user can follow the trajectory of different particles produced in the detector and can get an idea of the interplay between the different sub-detectors.

5.3 Particle Physics with Cosmic Rays

In the following chapters I present several initiatives to actively involve the general public, including high school students, in particle physics research. These programs support small experiments and allow for access to particle physics data in order to study them.

Nature provides energetic elementary particles for free – cosmic rays. Victor Hess discovered cosmic rays more than 100 years ago and cosmic ray studies are still a very active field of research. In order to detect cosmic rays, simple detection technologies can be used that permit the measurement of basic parameters of cosmic ray showers. Besides measuring the lifetime and flux of muons with a single setup, large detector arrays can characterise the broadening of such a shower and thereby estimate the energy of the initial particle generating the shower. In particular, studies of these extended air showers are of scientific interest. Several universities use this detection technology and its data analysis to educate their physics students. Recently, the same technology is also used to motivate high school students in particle physics. Several initiatives in several countries worldwide have started to cooperate with high schools in order to set up cosmic ray detectors in schools[4].

Today, nearly everybody owns a small cosmic ray detector; although they typically use it for a different purpose. Almost every mobile phone has a small built-in camera that is also sensitive to charged particles. Most of the cameras are based on a CMOS image sensor; a similar technique used in modern particle physics experiments. The size of each sensor is very small, but almost everybody owns one and simple software running on the phone permits synchronisation of the data with data taken by others. As a result, combined analysis can be performed. A reconstructed cosmic ray trajectory taken with the camera of a mobile phone is shown in Figure 7. Currently, several software packages for mobile phone cosmic ray detectors are available[5].

3 http://ippog.web.cern.ch/sites/ippog.web.cern.ch/files/import/cms_slice_elab.swf
4 Cosmic Muon Observer - http://physik-begreifen-zeuthen.desy.de/
The High School Project on Astrophysics Research with Cosmics http://www.hisparc.nl
5 https://wipac.wisc.edu/deco or http://crayfis.io

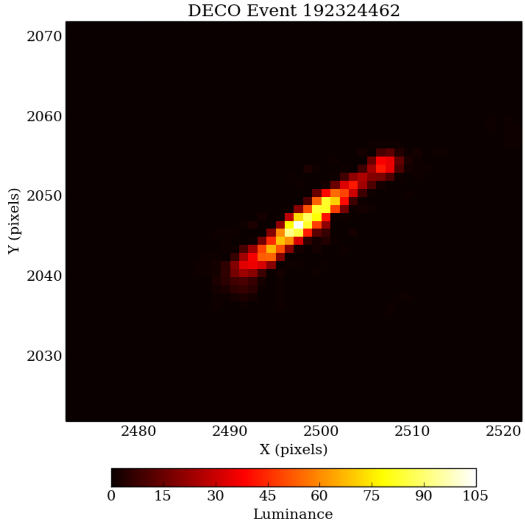

Fig. 7. Event display of a cosmic ray event reconstructed from data recorded with a camera from a mobile phone (Picture taken from Vandenbroucke et al., 2016).

5.4 Particle Physics with data taken by a LHC experiment – CMS open Data

Cosmic ray events are available for free, however the particles are not available in a controlled environment. In order to observe particle reactions in a controlled way in the laboratory, particle accelerators like the LHC have been developed. Recently, data from the CMS experiment have been made publicly available[6] and can be used for research and educational purposes. However, only part of the data set recorded by the CMS experiment is publicly available. The full data set will be only released after a reasonable embargo period.

The raw data taken by particle physics experiments alone is of limited use. The raw data needs to be prepared using complicated reconstruction algorithms and the interplay between the different sub-detectors needs to be taken into account. For this reason, the data is either released in a partially reconstructed form or together with the corresponding software in order to perform the necessary reconstruction. The data set is provided in exactly the same format as used by the scientist. The software can be installed via virtual machines, which allows for platform-independent usage. The data, together with the corresponding software, offers an excellent playground for preliminary research steps, which is much more powerful and flexible than simple visualization tools currently available, such as an event display. The data set is accompanied by a set of simulated data for advanced particle physics studies.

5.5 Higgs Hunters – help the scientists with your expert knowledge

One major component of experimental particle physics is data analysis and data interpretation. Signal processes must be selected from among many background events. The Higgs production cross-section, for example, is several orders of magnitude smaller than the total cross-section; identifying Higgs particles produced by a process is like looking for a needle in a haystack. For this selection process, modern multivariate analysis methods, such as

6 http://opendata.cern.ch/research/CMS

artificial neural networks, are used. The *Higgs Hunters*[7] initiative uses data taken with the ATLAS experiment at the LHC to engage the general public in the search for an exotic Higgs decay. Along with the data a simple search task is phrased: *"lines that seems to sprout from a common point that are not the center".* Standard reconstruction algorithms are not very efficient for such topologies, but the human eye is very good at pattern recognition and can easily spot such events. Classification by human eye is performed on data provided in the form of event displays. The program is accompanied by scientific background information and a blog-based discussion forum.

5.6 ATLAS@Home

Any scientific interpretation of data collected by modern particle physics experiments requires reliable simulation of the experiment performed. Experiments can only detect objects such as tracks from charged particles or entries in the calorimeter from neutral particles. Simulation provides a link between the underlying physics process and the objects observed in the detector. While events at the LHC are produced with a rate of 40 MHz, the simulation of a single event takes several minutes. The simulation can be divided into two different steps – the simulation of the physics process and the simulation of the interaction of the objects created in the physics process with the detector. Simulating the interaction of the objects with the detector requires most of the time. In addition, five to ten times more simulated data is needed on average, compared to experimental data. More than 50% of the available CPU-time used over the whole course of a particle physic research project is needed for simulation.

The project ATLAS@HOME[8] takes advantage of the extensive computer power that is available on almost everybody's desktop and yet goes unused. Interested users can download and install a free program to perform a simulation for the ATLAS experiment on their computer. The program is executed in a virtual machine on the computer and lasts between one and two hours, depending on the CPU power available. The user can earn credits corresponding to the CPU power provided and the credits are shown on a scoreboard displaying the most powerful contributors. Overall, the amount of simulated events provided by the ATLAS@HOME project relative to the professional computer centers is sizeable. The amount of simulated data, quantized in so-called jobs, subdivided for the different providers is shown in Figure 8.

The ATLAS@HOME project also provides additional scientific background information for the users. Users have the opportunity to learn something about the physics processes being simulated, the scientific context and experiment being performed.

5.7 International Masterclasses - Hands on Particle Physics

The program *"International Masterclasses – Hands on Particle Physics"*[9] is a program dedicated to teaching high school students the principles of particle physics. In addition to attending classical lectures introducing the principles of particle physics, the students apply the knowledge they gain to experimental data. Students classify events into certain event categories and perform simple analyses, such as determining a cross-section with the data. All of this is done under the supervision of particle physicists working together with the students. The particle physics processes are identified by event displays, mimicking the daily work of a scientist. Besides the underlying particle physics, students acquire knowledge about experimental uncertainties and the statistical behavior of quantum mechanical processes -something that can hardly be carried out during a lecture. Normally the event lasts for a complete day and is performed at a university or a research center. The program started in 1997 as a national program to promote particle physics for high school students in the UK.

7 www.higgshunters.org
8 http://atlasathome.cern.ch/
9 http://www.physicsmasterclasses.org

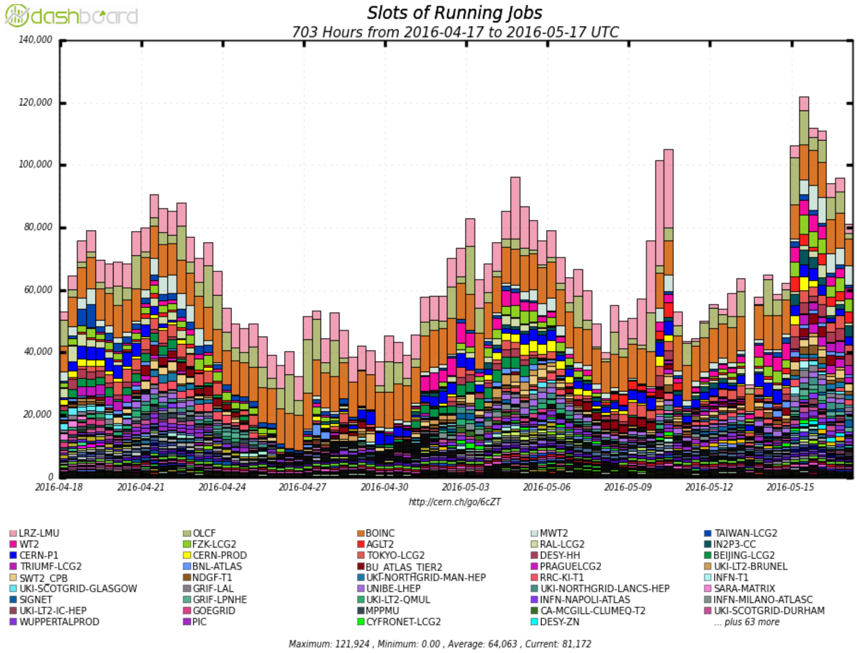

Fig. 8. Number of jobs, shown on the ordinate, as a function of time. The different color-codes represent the various computer centers providing simulated data for the ATLAS experiment. The orange entry, labeled BONIC, is the contribution of simulated events being provided by the ATLAS@HOME project (© ATLAS 2016 CERN).

Today the Masterclass program is a worldwide coordinated effort lasting about five weeks in spring. Every year about 10.000 high school students from more than 40 countries take part. After lectures and the hands-on part with simple analysis on real data the students have the opportunity to discuss their results and their experience with colleagues worldwide via videoconference. At some sites, the Master class program for students is accompanied by a dedicated program for high-school teachers only. The schedule is similar to the one for high-school students, including the hands-on part.

Recently, international Masterclasses on astro-particle physics were introduced as well. The concept follows the concept described above closely, with lectures and a hands-on part, now using data taken from cosmic ray experiments like the Pierre Auger Observatory[10] or the neutrino experiment Ice Cube[11].

5.8 Laboratory classes in the world leading particle physics laboratory - S'Cool Lab

Providing students the opportunity to experience experimental particle physics in the laboratory is the goal of the S'Cool LAB program at CERN[12]. School classes with students aged 16 to 19 can apply for a one-day visit to CERN. During the visit, students can perform several experiments related to the research being performed at CERN. These small-scale experiments contain topics such as the principles of particle acceleration or the observation of elementary particles with a detector. For this, CERN hosts a dedicated hands-on facility for high school students. Besides the hands-on part in the laboratory classes, the students have the opportunity to visit the experiments at CERN.

10 http://auger.colostate.edu/ED/
11 https://masterclass.icecube.wisc.edu
12 http://scool.web.cern.ch

5.9 Virtual Visits

Quite often, school classes cannot take a visit to CERN due to financial or logistical reasons. However, in order to give high-school students a glimpse into experimental particle physics, some LHC experiments offer so-called virtual visits[13]. Students get a backstage view from afar as well as the opportunity to discuss physics with scientists working at CERN. Scientists walk with a mobile camera through the laboratory and show parts of the experiment or discuss the information available in the control room of the experiment. To do this, only basic videoconferencing equipment and a fast internet connection are necessary.

6 Summary

The discovery of the Higgs-Boson at the LHC at CERN in 2012 is only an intermediate step towards a new physics theory beyond the standard model of particle physics. The standard model successfully describes most particle physics measurements in a self-consistently way, however, several other astrophysical observations clearly point towards a more fundamental theory.

The restart of the Large Hadron Collider during summer 2015 with an increased center-of-mass energy of 13 TeV makes it possible to open a new window towards new physics phenomena, paving the way towards a physics model beyond the existing standard model of particle physics. Exciting times are ahead of us.

In order for the general public to take part in this scientific excitement, dedicated outreach and education programs have been developed. In addition to the well-known instrument of public lectures, several developments based on multimedia aim to get students and general audiences interested and involved. The interactive access to experimental data goes beyond pure knowledge transfer and represents an important common feature of most of these initiatives.

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13 http://cms.web.cern.ch/content/virtual-visits and http://atlas-live-virtual-visit.web.cern.ch/atlas-live-virtual-visit/

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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 25–30). European Physical Society.

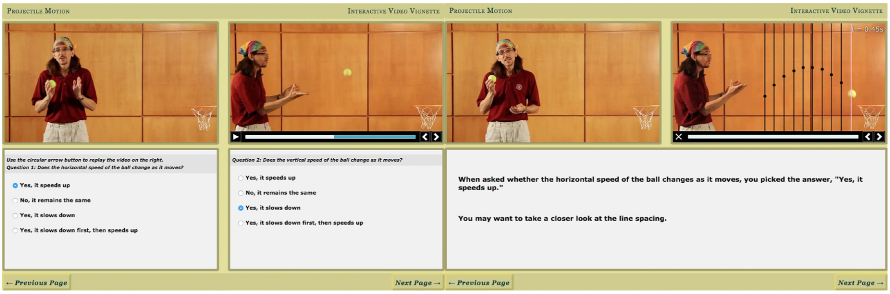

Fig. 1. Left: Two multiple-choice questions in the Projectile Motion vignette. Right: Results of video analysis, showing the student's prediction.

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.

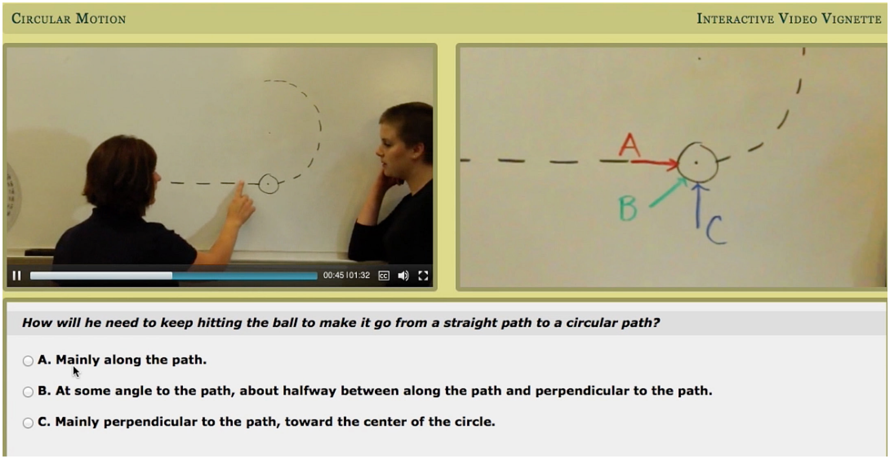

Fig. 3. The elicit stage of the Circular Motion vignette.

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.

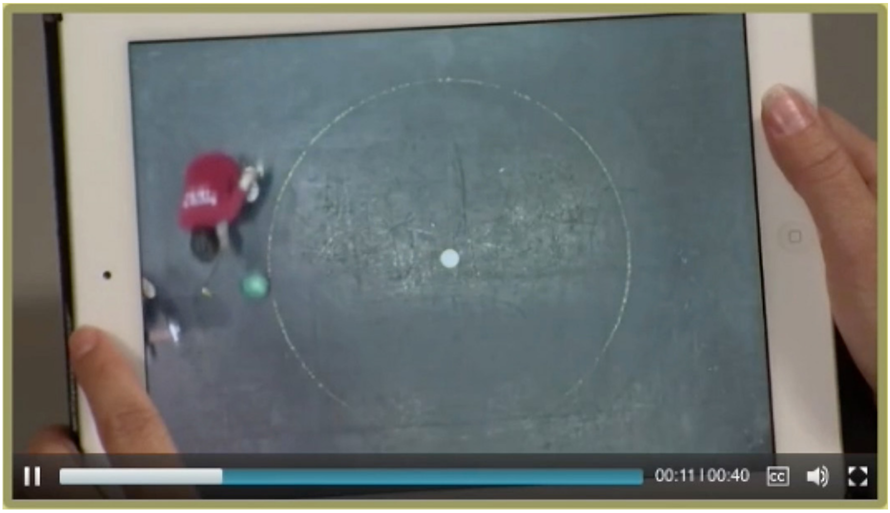

Fig. 4. The confront stage of the Circular Motion vignette. The instructor must tap the ball toward the center of the circle to make it follow a circular path..

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/).

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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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 31–38). European Physical Society.

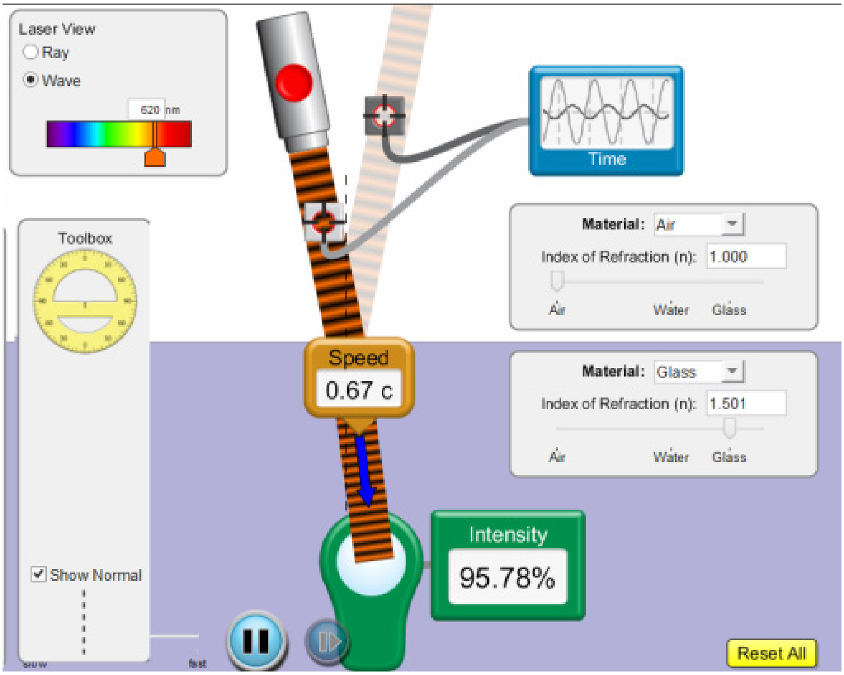


Fig. 1. Bending Light rich simulation screen.

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

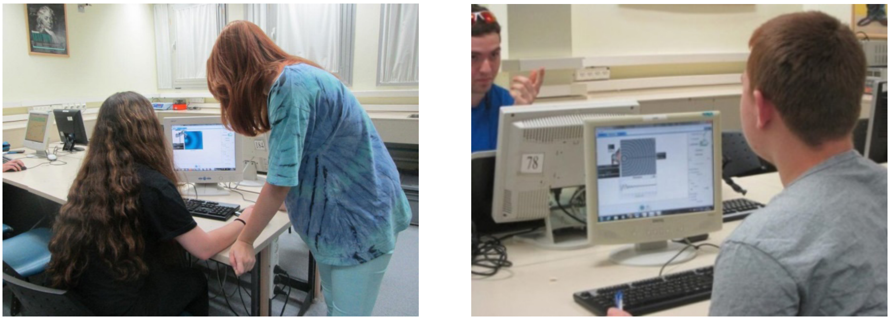


Fig. 2. Students exploring wave simulations.

"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^{o} 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

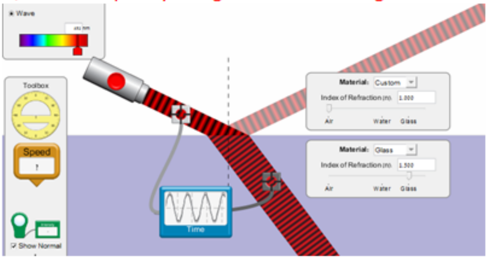
The collected questions and answers were analyzed using two approaches – an analytical approach and an interpretive approach.

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.

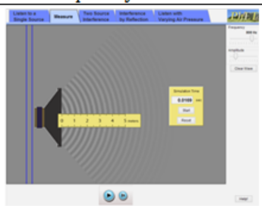
this process has yet to be completed. Fig. 3 shows an example of the analytical approach. To date we offer results for 223 questions, submitted by 17 students in the 2014 group. The questions were generated using the PhET simulations (https://phet.colorado.edu/en/simulations): *"Waves on a String"* and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

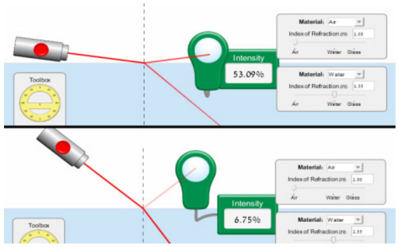
Using Tools

Q: How much time will it take a sound wave of 800Hz frequency to cross 5 meters?	Q: Does tension affect the wave's speed?
	

This type of question indicates a disposition towards using technological tools for discovering answers to questions. This disposition is important for executing a project.

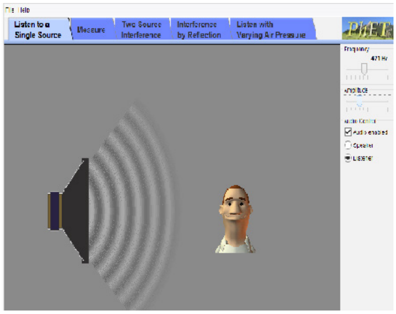
Gaining a Comprehensive View

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



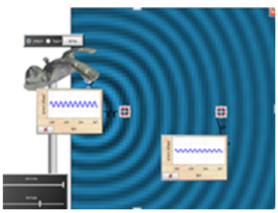
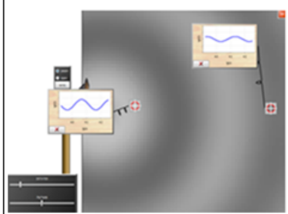
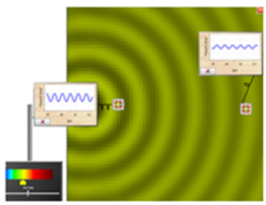
This aspect of refraction, often overlooked in classroom physics, is important for the design of optical systems. The simulation affords the learner an opportunity to experience this phenomenon both visually (by the color intensity of the partially reflected light) and quantitatively (by using the intensity 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?*



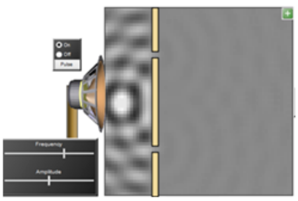
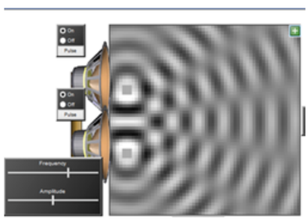
By selecting the listener as the audio detector, and changing the volume of the source from zero to a certain level, the student can experience the time lag between the sound source activation and the sound detection by the listener. It is important to note that in reality one rarely experiences this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

Recognizing Similarities

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

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

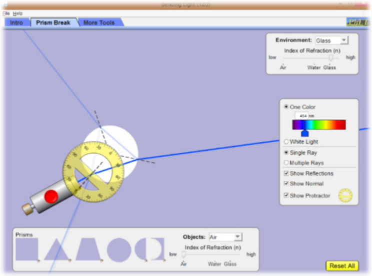
Exploring Alternatives

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

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?*

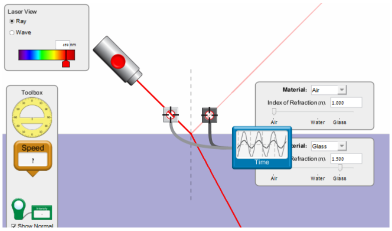


This unique question indicates a design attitude, highly useful for carrying out a project. The student uses the available components to create a desired outcome.

Problematic Issues

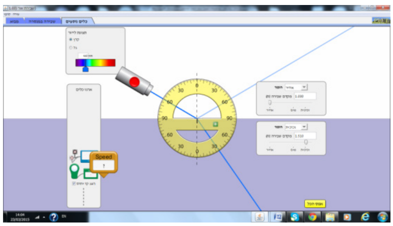
Simulations are driven by computational models which may be idealized or may have limited accuracy. Likewise, simulations may offer simplistic representations of measurements which are very difficult, or even impossible, to perform in reality.

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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Students’ Difficulties in Interpreting Images and Simulations About Astronomy Phenomena

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In this paper, we investigate difficulties for students in interpreting images and simulations in astronomy. To analyze images and animations we adopted the socio-semiotic theoretical framework by Kress and Van Leeuwen. This framework allowed us to categorize images and simulations according to their representational structures -namely, the way in which symbols and signs are organized for communication. First, six images from a textbook and two internet simulations were analyzed according to the framework. Then, we designed a 40-minute interview about the phenomenon represented in the images and the animations. Analysis of answers showed that difficulties are linked to the spatial distribution of symbols and signs, the presence of real/symbolic elements, and the relationships between different images. Our results may help to inform the design of visual instructional materials.

1 Introduction and aims

Most of today’s scientific (and non-scientific) communication is based on visual language. Consequently, teaching materials nowadays also increasingly exploit images and animations in order to improve students’ understanding of scientific concepts. Such an increased usage of images in school leads to a tension between the interests of offering teachers straightforward, short representations, and the need for more open challenges for students such as, e.g., meaning construction and problem solving (Pozzer-Ardenghi & Roth 2005).

In this paper, we investigate difficulties students encounter when interpreting images and simulations related to topics in astronomy. The main reason for this choice is that school textbooks progressively feature photographs of Earth, as well as schematic representations of the Sun-Moon-Earth system, and graphs (as the H-R diagram). Moreover, planetariums and science centers offer visitors realistic simulations using software packages such as Celestia, Starry Nights, and Stellarium.

At the same time, astronomy is a content area where students frequently hold a variety of a misconceptions as, for instance that seasons are due to Sun-Earth distance, or that the Moon phases are due to Earth’s shadow (Baxter, 1989; Trumper, 2006; Trundle, Atwood, & Christopher, 2002). Some authors have pointed out that the persistence of such alternative conceptions may be partly due to the difficulty of reading and interpreting the images commonly used in school textbooks (Pena & Quilez, 2001; Dove, 2002; Ojala, 1992; Lee, 2010). For this reason, the question that guided this study was as follows*: “Do images and animations about basic astronomical phenomena support or hinder learning of the related scientific content?”*

Testa, I., Colantonio, A., Galano, S., Leccia, S., & Puddu, E. (2016). Students’ Difficulties in Interpreting Images and Simulations About Astronomy Phenomena. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 39–46). European Physical Society.

2 Review of literature

The increasing use of pictures or graphical representations in science teaching raises the issue of understanding the so-called *"visual language"*, which features functions and structures similar to those of verbal language (Halliday, 1978; Kress & Van Leeuwen, 1996). The knowledge of the visual language is necessary to communicate in an appropriate manner and helps to acquire new information. Still images are the most elementary components of visual language used in the teaching of science. For instance, figurative images (illustrations) representing ideas or scientific concepts are widely used at primary and middle school level. As education advances toward the university level, science communication exploits more schematic and technical images. However, photographs, drawings, and diagrams in school textbooks and academic manuals do not guarantee greater effectiveness in communicating science contents since students need to know how to interpret the visual language of an image so that they can correctly infer its content (Roth, Bowen & McGinn, 1999; Roth, Pozzer-Ardenghi, & Han, 2005). For instance, some studies claim that students consider diagrams more useful than photographs in understanding scientific concepts, since photos may convey also hidden meanings (Kearsey & Turner, 1999; Pozzer-Ardenghi & Roth 2005). Moreover, according to other studies, images sometimes produce an effect contrary to that intended by the authors themselves, undoing the intention of the images in helping the explanation of a concept (Reid, 1990; Reid & Beveridge, 1990). Finally, there is sometimes disparity in visual representation systems (e.g. textbook images as opposed to teacher diagrams and gestures). In the following section, we describe the theoretical framework used in this study to analyze visual representations.

3 Theoretical framework

As evidenced by the above studies, since visual representations do not simply present objects and concepts, students cannot be passive receivers of such representations, rather, they are active interpreters. Written scientific communication is, in general, multimodal (Lemke, 1998), i.e., the visual language necessarily exists alongside with more traditional modalities of communication such as the verbal or the mathematical ones (Kress & Ogborn, 1998; Barlex & Carré, 1985; Jewitt, Kress, Ogborn & Tsatsarelis, 2000). For example, a frequently used modality is the verbal-visual one, where text is accompanied by one or more Cartesian graphs that detail the reported contents (Schnotz, Picard & Hron, 1993). The study of the symbols and signs (semiotics) used in the visual language may be useful in interpreting and predicting student' difficulties when dealing with images in science communication. For this reason, to analyze images and simulations, this study adopted a socio-semiotic theoretical framework inspired by the works by Kress and Van Leeuwen (1996).

The framework categorizes images according to the way in which symbols and signs are organized with the aim of expressing the intended concepts (Lynch, 1988). Two types of visual representational structures, narrative and conceptual, are defined (Figure 1). The narrative representation depicts a sort of *"transaction between participants in a temporary relationships"* and can be *"naturalistic"*, for example a drawing that represents a well-defined time of a day, or *"abstract"*, for example, the isobar curves indicating the weather conditions of a given day.

The conceptual representations may be of three main types: classificatory, analytical and symbolic. The classificatory representations define a relationship or a taxonomy of the represented elements: typical examples are tree diagrams that represent the hierarchical structure of an organization. The analytical representations define a relationship or a part-whole type structure: typical examples are road maps. Symbolic representations define a relationship based on a meaning provided by the reader: typical examples are expressionist paintings or mathematical equations.

The possibility of combining all these different types of representations may generate difficulties in the interpretation of the message(s) expressed in an image. This framework was developed and adopted within the STTIS (Science Teacher Training in an Informa-

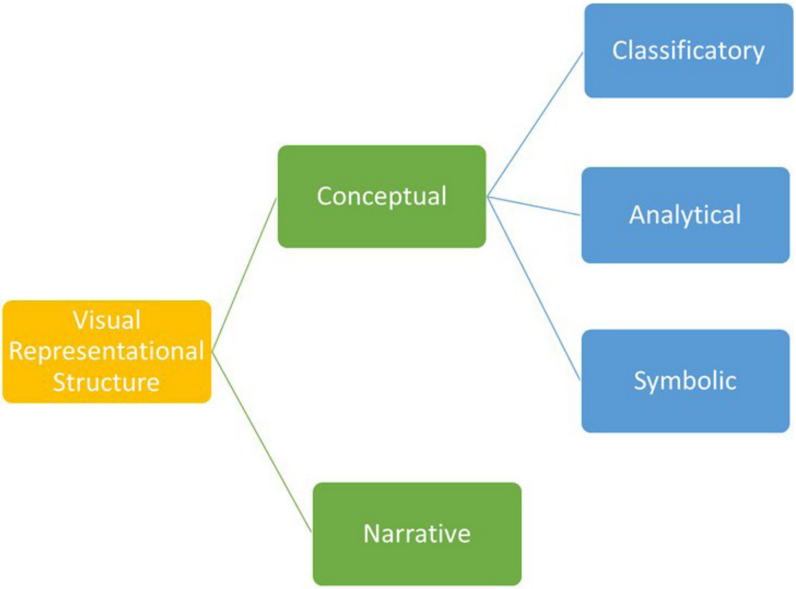


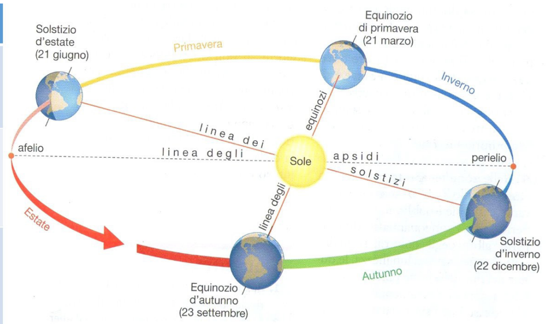
Fig. 1. Types of visual representational structures.

tion Society) project. The results of the research studies carried out during the project (Ametller & Pintò, 2002; Pintó & Ametller, 2002; Stylianidou, 2002), led to the definition of a list of iconic features that may be sources of difficulty when reading and interpreting documents containing different types of visual representations.
The visual features relevant to this study are as follows (adapted from Pintò, 2002, pag. 231-232):

- Elements representing both real world and schematic or symbolic entities (R / S)
- Elements to be selected or conceptually highlighted in relation to textual/graphical features, which do or do not make them salient (SEL)
- Elements requiring appropriate reading of symbols, and which contain examples of synonymy, homonymy and/or polysemy of symbols (SYM)
- Presence/absence of verbal elements to be read as an important part of the image, such as captions (VER)
- Presence of two or more conceptually related images (INT)
- Structures that require the interpretation of the spatial distribution of symbols and signs (CST)

The R/S, SEL, SYM and VER categories represent local iconic features of an image, whose meaning is independent of the specific image in which they are used (for example, the verbal element "m/s" in a Cartesian graph always indicates the measure of speed, regardless of the appearance of the curve represented in the graph). The INT and CST categories represent global iconic features of an image, whose meaning depends on the image in which they are used (for example, specific s (t) and v (t) graphs that refer to the same motion). The above list permitted explanation of well-known difficulties for students in the interpretation of kinematic graphs (Beichner, 1990) and images regarding geometrical optics (Colin, Chauvet & Viennot, 2002). Moreover, the list was useful in analyzing students' difficulties when dealing with real-time experiments (Testa, Monroy & Sassi, 2002). Figure 2 and 3 show the application of the framework to one of the chosen images from the textbook by Palmieri & Parotto (2012) and to one of the two chosen simulations about change of seasons.

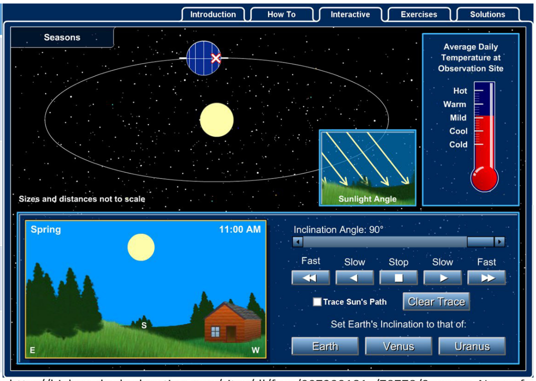
Conceptual difficulty	Element of the List
The image emphasizes the ellipticity of the Earth's orbit and could lead to a wrong justification of seasons (Ojala, 1992)	Spatial structure (**CST**)
The four positions of the Earth, which mark Equinotia and Solstitia, are shown together in the same diagram, even if they refer to different times.	Spatial structure (**CST**)
Missing indication of the tilt of the Earth's axis, indication of elements that are not important for explaining seasons (days, solstitia line, equinotia lines, aphelion and perihelion)	Verbal Elements (**VER**)



Reproduced with permission from Palmieri E. L. and Parotto M. 2012 Scienze della Terra (Bologna: Zanichelli)

Fig. 2. Analysis of the textbook image "Seasons".

Conceptual difficulty	Element of the List
Role of the Planet's axis on seasons: need to explicit that the view in the main frame is from outer space	Selection of features (**SEL**)
Relationships between images of planet' s orbit, the Sun path, the house and the sun's rays	Presence of two or more images (**INT**)
Sun' s rays represented as parallel arrows in the small frame	Similarity of symbols (arrows, circles, rays) (**SYN**)
Effects of axis' tilt on planet's temperature represented by a thermometer	Presence of schematic and realistic representations (**R/S**)



http://highered.mheducation.com/sites/dl/free/007299181x/78778/Seasons_Nav.swf

Fig. 3. Analysis of the simulation "Seasons Navigation".

4 Methods

As a research tool, we adopted 45-minute semi-structured interview in which, for a given textbook image or simulation, students were asked a question about the represented phenomenon. The student could answer the proposed questions with words and drawings, using all information he/she had about the particular phenomenon. The interviewer focused on the iconic features of the image or simulation. Six images and two simulations were used. Two images were about seasons (*Seasons and Sun's rays), two about eclipses (Eclipses, Eclipses Frequency), and two about moon phases (Phases of the Moon, Dark Side of the Moon). The two simulations were about changes of seasons (Seasons Ecliptic, Seasons Navigation). Example question for the simulation "Season Ecliptic"*[1] is reported in Figure 4.

Two groups of students participated in the study. Eighteen students (17-18 years old) who participated in a 12 hour out-of-school activity at the Capodimonte Astronomical Observatory in Naples were interviewed about textbook images (Group 1). Sixteen students (16-17 years old), who participated in eight hour out-of-school activity at the Department of Physics of Naples, were interviewed about simulations (Group 2). Both groups had already studied basic concepts of astronomy before the visits.

1 http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.swf

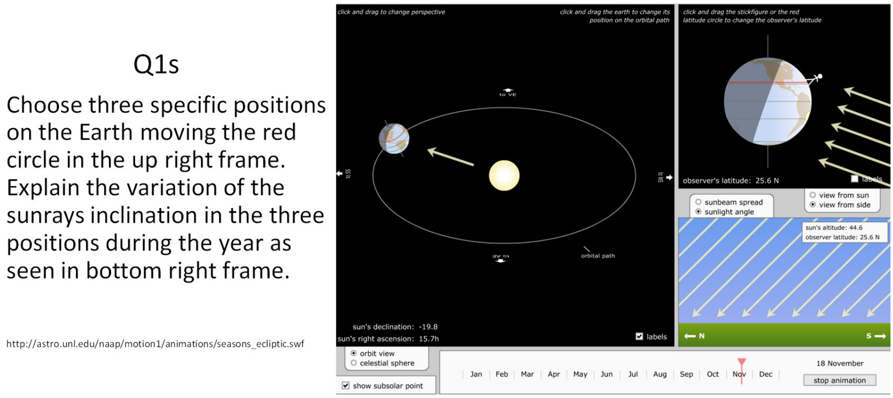


Fig. 4. Example question on simulation "Season Ecliptic".

Image/Simulation	Correct	Not Correct	Total
Seasons	5	13	18
Sun's rays	8	10	18
Eclipses	6	12	18
Eclipses frequency	1	17	18
Phases of the Moon	2	16	18
Dark side of the Moon	3	15	18
Seasons Ecliptic	10	6	16
Seasons Navigation	8	8	16
Total answers	43	197	140

Tab. 1. Distribution of students' answers to the interview.

5 Results

The number of correct and incorrect answers to interview questions is reported in Table 1. The analysis shows that the students encountered many difficulties in interpreting the textbook images. The percentage of correct answers is on average less than 25%. Students had difficulties explaining eclipses and moon phases.

The percentage of correct answers is slightly higher for questions on the simulations about the mechanism underlying the change of seasons.

In the following, we report students' answers about two images (*Seasons*, *Phases of the Moon*) and one simulation (*Seasons Ecliptic*) that are problematic from the iconic viewpoint.

- Image *Seasons* (Figure 2)

  M3: ...in the Northern Hemisphere it will be summer when the sun's rays are more directed toward the Tropics, it will be summer when the orbit is at the lowest point...
  I: What do you mean by the lowest point of the orbit?
  M3: when we project the ellipse, we have a segment...the highest point represents the maximum distance...

- Image *Phases of the Moon* (Figure 5)

  I: Can you tell me from this image, what phase of the Moon the two observers (red and yellow dots) will see?

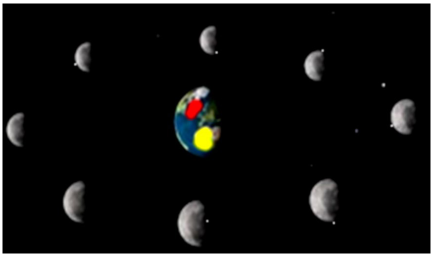


Fig. 5. Image "Phase of the Moon".

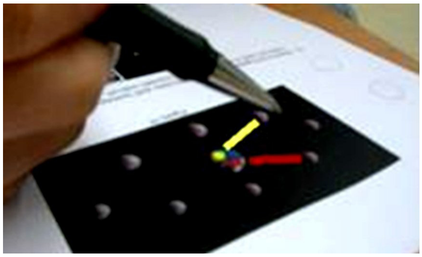


Fig. 6. Students' drawing to answer to a question about the image "Phases of the Moon".

F9: Well, the person indicated by the red dot will see the waning crescent Moon, while the person indicated by the yellow dot will see the waxing crescent Moon
I: So the two persons will see different Moons, right?
F9: Yes, because they have a different Moon on their vision line
I: Can you draw these lines?
F9: sure…the lines connect the dots to the Moons.. (Figure 6)

- Simulation Seasons Ecliptic (Figure 4)

M14: when we are in aphelion, the Sun heats the Earth more…
I: …did you infer this from the image?
M14: No, I already knew it..
I: …so, what happens when you run the simulation?
M14:… Mhhh. I see that when the simulation is running the change of sunrays inclination is due to the change in the velocity of the Earth along the orbit..

I: Does this simulation help you to justify change of seasons?
F1: yes, when we change the observer's position on the Earth, the inclination of the sunrays is different..
I: Ok, I see… but what can you infer from this?
F1: …when I move the Earth along its orbit, the inclination of the sunrays vary, so the same thing is happening… therefore… seasons are due to the motion of the Earth and the inclination of the Earth's axis…
I: Yes… but what is the role of the red circle in the upper right frame?
F1: …it is the parallel on which the observer lies…
I: …is it important the red circle to understand the seasons' phenomenon?
F1: .. I don't know… maybe it is a way to better indicate the observer and his movements on the Earth….

6 Discussion and implications

Results reported in Table 1 show that most of the chosen textbook images did not help students to grasp the represented concept. This finding confirms the difficulties generically pointed out in previous studies about students' alternative conceptions on these phenomena (Oyala, 1992; Pena & Quilez, 2001; Dove, 2002). Furthermore, analysis of the answers provided suggests that students' difficulties in reading and interpreting the proposed images are plausibly linked to specific iconic features of the images, namely the spatial structure (CST), the presence of real/symbolic elements (R/S) and of different images in the same iconic frame (INT). In particular, the spatial structure of the proposed images may have led the students to construct an incorrect or inadequate geometric model of the represented phenomena.

Apparently, students had fewer difficulties when dealing with simulations than textbook images. This evidence likely suggests that the possibility of changing parameters in the simulations may have helped students in the global interpretation of the phenomenon

However, in some cases, the emphasis on the evolution of the phenomenon led to some difficulties in identifying the role of iconic elements of the simulation (SEL).

Overall, iconic difficulties common to textbook images and simulations included:

- contemporary presence of temporal and spatial sequences representing different situations in time and space (e.g., Moon phases or the four seasons represented in the same image);
- differences in visual representation to be represented in the same image or simulation (e.g. the 8 phases of the Moon represented altogether or simulations of the Earth's orbit and sun's rays over seasons)
- the presence of iconic features that represent different scientific ideas or concepts (e.g. curves representing the Moon's orbit and the plane of the orbit represented together) the presence of hidden or implicit graphical features, which should be recognized/identified/selected in order to correctly interpret the image (e.g. the Sun not present in the Moon phases schema or in the sun's rays frame of the seasons simulations);

In general, our findings suggest that in teaching astronomy, teachers should take into account students' difficulties when viewing textbook images and when exploiting interactive simulations. We suggest teachers better characterize the use of simulations, refine their educational goals and integrate them with the widely used textbook images. In this way, multiple representations with particular features may be integrated to offer different perspectives that could be coordinated to improve students' learning outcomes. Similarly, since science understanding involves multiple, multi-modal representation and coordination, astronomy education should stress the relationships between visual representations and other semiotic resources (e.g., teacher's gestures).

In conclusion, this study may be a useful starting point for researchers who are involved in designing academic courses in astronomy based on printed images and simulations, such as those used in programs like Stellarium and Celestia.

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Application of Computer Simulations in Modern Physics Education

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Teaching modern physics is an essential yet challenging part of our curriculum. While introducing the main scientific theories and discoveries of the past century we often find ourselves with a lack of experimental resources. My goal is to develop and test computer simulations that can be used in high school education as a virtual science lab, where students are able to measure and experiment with modern physics phenomena. In most cases, the technical conditions for real student experiments are not met, or the observed phenomenon occurs over a time-scale that is inaccessible to observation (i.e. either ultra-fast or ultra-slow). However, a simulation is able to complete the students' experience already grounded in real observation.

1 Introduction

There are at least four essential questions which must be answered according to modern educational theories: "What shall we teach?" "To whom shall we teach those subjects?" "When shall we teach it?" And finally, "how shall we teach it?" These questions are fundamental to all subdisciplines, of course, but they are particularly problematic for modern physics.

In this paper, I introduce the main challenges to teaching modern physics in the Hungarian curriculum and give an idea and working plan for how to introduce computer simulations for more successful teaching. I will give an example of how a concrete simulation can help out as a teaching resource in classrooms and what the key points of its usability are.

This paper also provides a brief overview on the current goals of my future PhD studies and thesis. In that work, I wish to develop and test several modern physics simulations in high school physics classes, and observe their effects on students' motivation and performance.

1.1 Teaching Modern Physics in General

I'll begin with perhaps a seemingly dramatic question: "What is modern physics?" There are several definitions used for this term, e.g. "physics based on new theories found in the early 20th century", "physics used for understanding the underlying processes of the interactions of matter", "physics currently in development" or "physics used for our increasingly common modern tools".

This last definition highlights a key aspect of teaching modern physics: motivation. It is without question that motivating our students to study or even love physics is one of the biggest challenges in education today. There is certainly a great deal of literature on how to develop teaching methods to enhance motivation, and most of those ideas can be implemented in other subjects as well. Teaching physics, however, – or science in general – will always involve experiments to gathering knowledge. *"Performing experiments is the basic and most common method of scientific research and education. […] Experiments are typically*

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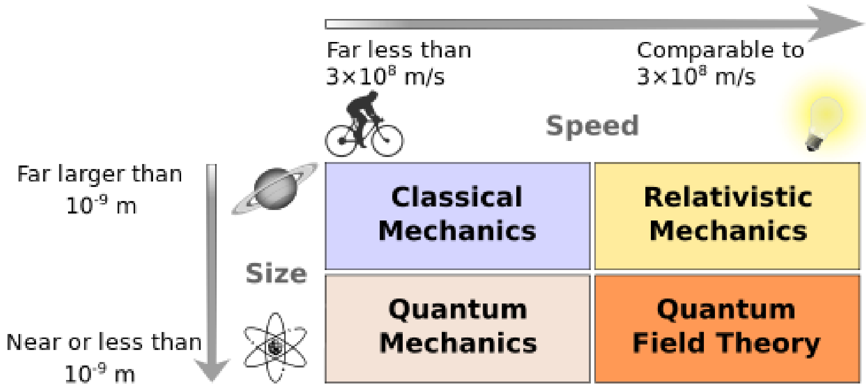

Fig. 1. Sub-disciplines of physics [2].

the foundation for determining the laws of physics and chemistry, and are the only (exclusive) tool for validating these deduced laws, hypothesises and theories. They also serve as the diagnostic tool for the limits of their validity." [1] This is an excerpt from the 1997 published Encyclopedia of Pedagogy. It clearly shows how important scientific experiments are in our physics education but that they are also a key part of keeping students motivated.

The constructivist approach toward teaching, in particularly inquiry-based learning/teaching (IBL) – goes even further, claiming that experiments should always be executed by the students. In this approach, students are permitted to form their own experiences, by observing, measuring, and drawing up hypotheses before validating them on their own. This seems to be an ideal approach for motivating and teaching physics to our students. As for modern physics I believe it is motivating itself. Most of the personal student referrals from my classes state that modern physics was the students' favourite part of our physics curriculum; there are even students who admit that learning about modern physics was the first time they ever considered studying science in the future. From this we can conclude that motivation is manageable, although there is another type of challenge in teaching modern physics, as we are about to see.

There is a really informative diagram on Wikipedia that summarizes another problem, which has to do with scales:

In classical mechanics we are working with relatively slow speeds and macroscopic sizes, which makes experiments easier to handle for students. The IBL approach to teaching physics works with a question-observation-hypothesis-experiment-answer system, where students are able to do their own experiments in nearly every lesson, not to mention the possibility of bringing these experiments home, as homework projects for example.

But processes in modern physics (if we treat everything outside of classical mechanics as modern physics) happen at high speed or/and small size scales. This alone makes experimentation difficult. In addition to these difficulties, however, is the theoretical challenge of being far removed from our everyday-approach theories (for example, wave-particle duality, the theory of relativity, mass-energy equivalence, etc.) Students don't observe electrons; they only observe traces of electrons, or signs of traces of electrons, like a number on a counter.

Time and number scales are also an issue, since the time of an event is often too slow (as in radioactive decays), too fast (as in Brownian motion or again, certain types of radioactive decays), or it consists too many participants, (as in photocells, or, again, Brownian motion and radioactive decays).

These are the reasons why showing modern physics experiments is extremely difficult in a classroom. Even with very creative experimental tools, the cost of these tools would preclude anything but very rare experimental presentations from the teacher.

Another key problem in addition to the above is the lack of time, an issue for which I will give a brief overview in the next section, although this discussion will be specific to the Hungarian system.

1.2 Teaching Modern Physics in Hungary

The Hungarian physics curriculum is currently under development, but there are some major aspects that seem constant. The physics curriculum consists of a huge amount of sub-disciplines throughout the five years of academic physics studies, and only in the last term is there any modern physics content, as seen below:

- 7-8th grades (12-14 yrs.): a brief overview without modern physics
- 9th grade (14-15 yrs.): dynamics, fluid dynamics
- 10th grade (15-16 yrs.): thermodynamics, electrostatics, direct currents, magnetic field
- 11th grade (16-17 yrs.):
  - oscillations, waves, electromagnetism, alternating currents in the first term
  - optics, astronomy and *modern physics including photoelectric effect, blackbody radiation, relativity, atomic models, nuclear physics* in the second term

With two 45-minute lessons a week, this allows for approximately 25 effective lessons on each of these topics. My personal experience is that teachers often do not adhere strictly to the above curriculum, and that these topics are ultimately shifted even more. It is not uncommon for students to finish high school without hearing anything about modern physics. As noted above, this is the science we use and develop today. There is an ongoing educational experiment at the moment with a new experimental textbook for students in which they introduce modern physics at earlier grades. Since no results from this study are available yet, I will confine my discussion to the time frames above.

In the next section I will provide an explanation as to how computer simulations can be used to address the concerns above, and will also provide new methods and ideas.

1.3 Introducing Computer Simulations

Regarding the theoretical challenges above, computer simulations always give us simplified images which could be visually helpful in the process of understanding. There are recent studies of how we can simplify even particle physics and make experiments in teaching modern physics, making it understandable to even the youngest student groups. I refer for example Gerfried Jeff Wiener, who developed a method of teaching particle physics with theoretically accurate pictures in smaller grade classes [3]. It is vital to keep all these simplifications in mind. The picture of a ball-shaped electron in a computer simulation can easily detract from the students' conception of the electron based on their wave function. There is no doubt, however, that understanding is improved when students' see something leaving the cathode, rather than a trace or a counter.

With the previously mentioned scales in time and numbers, we have a great deal of freedom in these two dimensions. One of the important options of using a computer simulation is that we can set the time scale dynamically, allowing functions that, for example, switch between time lapses (to, e.g., speed up or slow down a reaction), pause or even turn back in time. Also, we can work with a lot of particles simultaneously —certainly not as many as in real life, but there are great methods which work well statistically.

It is clear now how these simulations can make up for the lack of experimental tools in high school physics laboratories. Of course, a simulation will never be able to fully replace the educational role of a real-life experiment. However, seeing an electron beam's trace on a fluorescent plate is visually similar to seeing it on a computer screen, while in the latter case students can also investigate the phenomenon's basic principles and perform their own measurements. This final option brings us to the possibility of expanding our classrooms' borders, creating virtual laboratories and helping students to do experiments at home, for long-term project work or further analysis of a problem. Internet-assisted teaching can help resolve the issue of time frames, not only extending teaching time, but also allowing for adjustment to the students' needs.

If we strictly keep an eye on the goals to help out high school physics education, a good simulation would have the following attributes:

1. *Accessibility*. A simulation should be available to run under all the students' current devices, including smartphones, tablets and notebooks, and under any operation systems without using separate applets. In 2015, the majority of the popular browsers dropped support for NPAPI, which impacted plugins for Java (only the applets) and Silverlight. This would require the majority of the current physics simulations to be rewritten for broader usage. With the rapid proliferation of smartphones and tablets, we should introduce our students to teaching resources available on these platforms. Simulations written in HTML5 don't require applets, and are therefore considered safe.
2. *Diversity*. Simulations applied to high school education should offer various activities to the students and the teacher. This will make them easier to implement in the lessons and easier to personalize. This wealth of activities will also allow teachers to differentiate and lengthen the time allowed to student experimentation. A simulation that takes more time to prepare during a lesson than actually working with it usually is not worth the time, and a few minutes are always required just to introduce how the controls work.
3. *Simplicity and challenge*. Students are different, consequently simulations should have different layers of difficulty adapted to the diverse level of abilities and motivations, and help teachers to differentiate. Not all students will deeply understand the method behind a measurement, and not all of them will be satisfied with only a dynamic animation. The layers should be easily separated to avoiding confusing students.

Not many of the current simulations meet these conditions. When I looked up simulations on a specific phenomenon – the photoelectric effect –, I found that only one of the five most popular simulations was based on HTML[4]. The other four required downloading an applet or adding the webpage to the browser's list of exceptions. This requires a careful preparation for the simulation-supported lesson, and a lot of problems when it comes to the students' own devices.

The lack of diversity and possible student activities was also a common problem. It doesn't mean that the simulations were wrong at all, it just means sometimes the only possible way of using them was a brief show or trial. Only one simulation offered an idea on possible classroom differentiation, while the others were too simple or too difficult to understand for students.

A pleasant surprise was that three out of five of the most popular simulations offered the option of measurement. Trying these out in my classes I found that only one (the PhET simulation) can be used effectively, but it lacks a helping grid for recording the data, so real rulers were needed for the students to make their calculations.

Out of the five simulations, the PhET simulation was the most complex, which wasn't a surprise, knowing how much research and effort was invested in their work, but there were some points missing, such as accessibility and some extra features in student measuring exercises. My main motivation in creating a new simulation of this phenomenon was to add these functions.

1.4 Application of a Simulation on Photoelectric Effect [5]

I used the JetBrains WebStorm free and professional program to develop the simulation. It works with HTML5, which means you can run this on any device, including smartphones. The simulation adapts to the device we are running it on, rearranging the simulation plane and the icons.

The main functions of the simulation are simple. Students can set the desired cathode material they are experimenting with, as well as the wavelength and intensity of the light. The light efficiency can also be adjusted to define the percentage of the photons that pro-

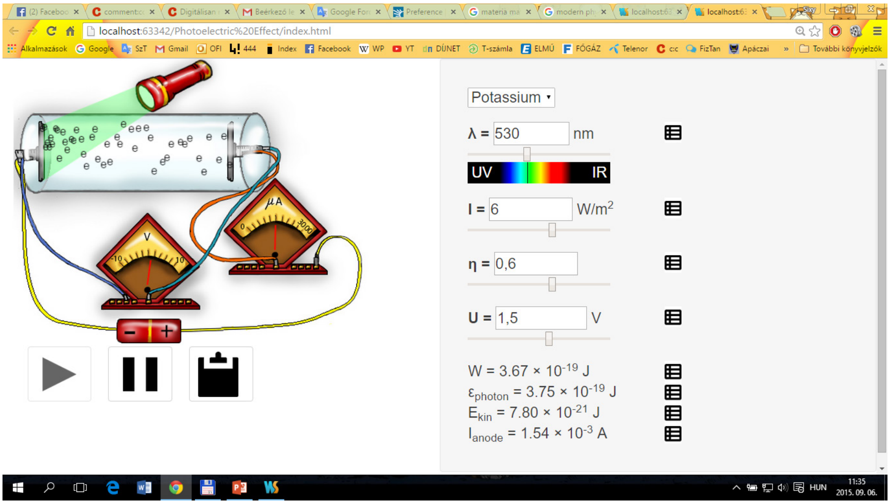

Fig. 2. My simulation on the photoelectric effect.

duce an actual photoelectric effect. The simulation provides all data, and the students can set an animation with (non-ball-shaped) electrons – slowly – moving towards the anode. The students can also give an accelerating or decelerating voltage on the photocells, thus making the electrons stop and turn back.

The strength of the simulation is the possibility to make simulated measurements with the side icons. Students can save any or all data to a chart. Every time any of the settings are changed, the data will be created in a new column. After the end of the measurement, students can export it to an Excel file, and can freely work with it. There are many possible measuring practices: for instance wavelength versus kinetic energy, or wavelength versus closing voltage which we can use to measure Planck's constant.

Also the simulation can show a one-dimensional view on the space charge effect. It means if there is no forward voltage applied, the negatively charged electrons form a cloud close to the cathode, repelling the new electrons leaving it, limiting their numbers. This is one of the main reasons why a forward voltage shall be used to make the photocell work. This phenomenon is something which talented students can observe, then learn about it from other sources, getting a deeper knowledge on the photoelectric effect. Differentiation can be done here with asking the students to experiment with the slider at the bottom and adjusting the space charge effect. The simulation calculates the value of the amperage by counting the number of electrons hitting the anode in a time interval. We can help our students by asking questions on their observations, i.e. 'how does the amperage change when enhancing the space charge effect?', 'how does it change when enhancing the forward voltage?', 'what is the difference in the value of the amperage between a strong space charge effect with maximum forward voltage and no space charge effect with no forward voltage?'. The answer to the last one is there is no difference. This observation can help students understand why the application of a forward voltage is important. As the simulation is one-dimensional, it does not include the stretching of the electron beam (which is an important phenomena in particle accelerators)[6].

2 Impact on Students' Performance

For observing the simulation's impact on students' performance I also give them an exercise on the topic taken from the Hungarian physics graduation exams, where they have to find the wavelength limit, the speed of emitted electrons and the stopping voltage of a

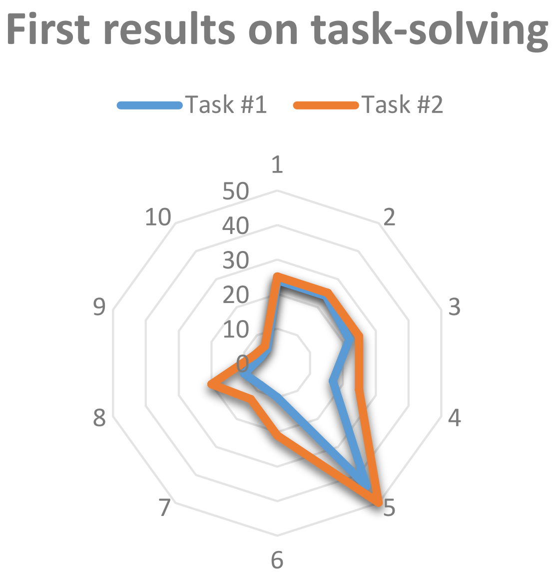

Fig. 3. First results on solving a calculation task about the photoelectric effect.

given photocell. Then, without any further discussion they are introduced to the simulation with a user's guide on its key functions. Then, after several minutes of independent work, they are asked to solve a similar exercise. The first results were recorded in two half-class sized group with a total number of 27 students. I used the authorized correction key provided for the original graduation exam and split the total 12 points into 10 parts, as the correction key did the same. Then added all up the points of the students before, and after working with the simulation. They used it for only 25 minutes though (with 10 minutes for each task). Usage of a calculator and also a table consisting the primal scientific functions and laws – as in the real exam – were allowed. The results can be seen on Fig. 3 below:

As one can see, all the parts showed slight or bigger improvement. The students didn't get any help on how to solve the problem between the two parts besides using the simulation. The three biggest difference were on the 4th, 6th and 8th part of the task. The 4th one was the last part of the first question, about findig the wavelength limit. The 6th (and 7th) one was the last part of the second question, about finding the speed of the emitted electrons. There weren't much difference on parts 1-3 and 5. These points were given for finding the correct physics laws and writing down the needed equations. Points 4 and 6-7 were given for using and transforming the equations to find the solution. As the equations were known (or could be looked up in the table of functions) this is hardly a surprise. It is comforting though that the simulation helps to make these equations getting understood. The 8th part (containing two points) was understanding how the stopping voltage works and writing down the correct equation. This was the hardest one for the students, but many gave good explanations after using the simulation, for instance „the energy loss of the electron in the field of the stopping voltage equals it's initial kinetic energy" - even though not being able to find the correct relation between the energy and the voltage ($U{\cdot}e$).

There are examples on giving more detailed and more correct explanations on the calculated problem after using the simulation.

The research was done on a regular physics class without previous notification of the students. This means a vast part of the students were naturally unprepared for it, though they were all introduced with the topic and calculation examples before on the previous classes.

3 Conclusions

Of course, further investigation is needed for a complex view on the efficiency of using these simulations, but my initial feedback shows that even if the performance on solving the concrete task doesn't change, the students' answers are more complex and precise – both in writing down equations and in trying to explain the phenomenon. I believe computer simulations are not the exclusive method, but a great resource as teaching materials, helping in many of the challenges we face while teaching modern physics.

Acknowledgments

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4. The checked simulations were:
   http://lpscience.fatcow.com/mgagnon/Photoelectric_Effect/photoelectriceffect1.htm
   http://lectureonline.cl.msu.edu/~mmp/kap28/PhotoEffect/photo.htm
   http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=342.0
   http://www.walter-fendt.de/ph14e/photoeffect.htm
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Creating Electronic Books-Chapters for Computers and Tablets Using Easy Java/JavaScript Simulations, EjsS Modeling Tool

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This paper documents the process (tools used, design principles derived and modeling pedagogy implemented) of creating electronic book-chapters (epub3 format) for computers and tablets using Easy Java/JavaScript Simulations (formerly EJS, new EjsS) and Modeling Tool. The theory underpinning this work is that learning by doing through dynamic and interactive simulation-models is more easily integrated than knowledge gained through static printed materials. I started by combining related computer models with supporting texts and illustrations into a coherent chapter. From there, a logical next step towards more complete support for teachers and students is developing prototypes for electronic chapters on the topics of Simple Harmonic Motion and Gravity. This also is customized for the Singapore-Cambridge General Certificate of Education Advanced Level (A-level). I aim to inspire more educators to create interactive and open educational resources for the benefit of all.

1 Introduction

After the Singapore Easy Java/JavaScript simulations and EjsS Modeling Tool workshop organised by Francisco Esquembre and Wolfgang Christian on November 25-28 2014, I started combining related computer models with supporting texts and illustrations into a coherent chapter. a logical next step towards tighter support for teachers and students. This paper aims to articulate some of the design ideas and tools used, as well as a mathematical modeling approach (Wee, 2014) developed to work in EjsS, similar to Tracker's video analysis kinematics model (Brown, 2012; Wee, Chew, Goh, Tan, & Lee, 2012; Wee & Leong, 2015; Wee, Tan, Leong, & Tan, 2015). Some examples in the e-chapter will be mentioned and, in conclusion, I hope to inspire more educators to create interactive and open educational resources (ISKME, 2008) for the benefit of all.

2 Tools Used

Table 1 shows the tools used to create these interactive epub3 format electronic text book chapters, where EjsS Modeling Tool (Esquembre, 2012) is heavily relied upon to generate these *.xhtml format texts and JavaScript simulations. Since EjsS Modeling Tool does not create the *.xhtml format texts, but rather simply packages it with the JavaScript simulations, a separate xhtml editor such as BlueGriffon is used to create these texts with markup errors removed. Moreover, to generate free MathML format equations, I recommend using MathtoWebonline to create these equations and paste them into the *.xhtml files-texts-equations inside the BlueGriffon editor. Authors who wish to publish their e-chapters on Apple iBook should note that pictures need to size exactly to 1024x768 in dimensions.

Wee, L. K. L. (2016). Creating Electronic Books-Chapters for Computers and Tablets Using Easy Java/JavaScript Simulations, EjsS Modeling Tool. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 55–60). European Physical Society.

	Computer Tools	Purpose
1	EjsS Modeling Tool	Make interactive models, generate epub
2	BlueGriffon xhtml editor	Create remove markuperrors *.xhtml files with texts, images (recommend 1024x768), insert equations MathML
3	Mathtowebonline MathML equation editor	Generate equations in MathML format

Tab. 2. Tools used and their respective purposes towards creating interactive textbook chapters.

3 Simulation Design Principles for electronic book-chapters

In the process of creating a suite of simulations for 2 chapters on Simple Harmonic Motion and Gravity (Wee & Goh, 2013) customized for the Singapore-Cambridge General Certificate of Education Advanced Level (A-level), three design principles (Wee, 2012; Wee & Goh, 2013; Wee, Lee, Chew, Wong, & Tan, 2015; Wee & Ning, 2014) emerged while preparing this paper; they are listed below.

3.1 User design: Simple & Optimum View of Screen

To create a user interface and view for optimized intellectual performance by students, cognitive load theory (Roth, 1999) suggests the simulations to be designed with a simple layout with less user control interface. Figure 1 shows a simple 2 panel layout and a bottom control panel that was well received by teachers and students in Singapore.

In addition being simple in view, I have implemented full screen capability on Android to allow tapping on the smaller screen size of students' personal hand phones. These devices can then be used for learning anytime and anywhere.

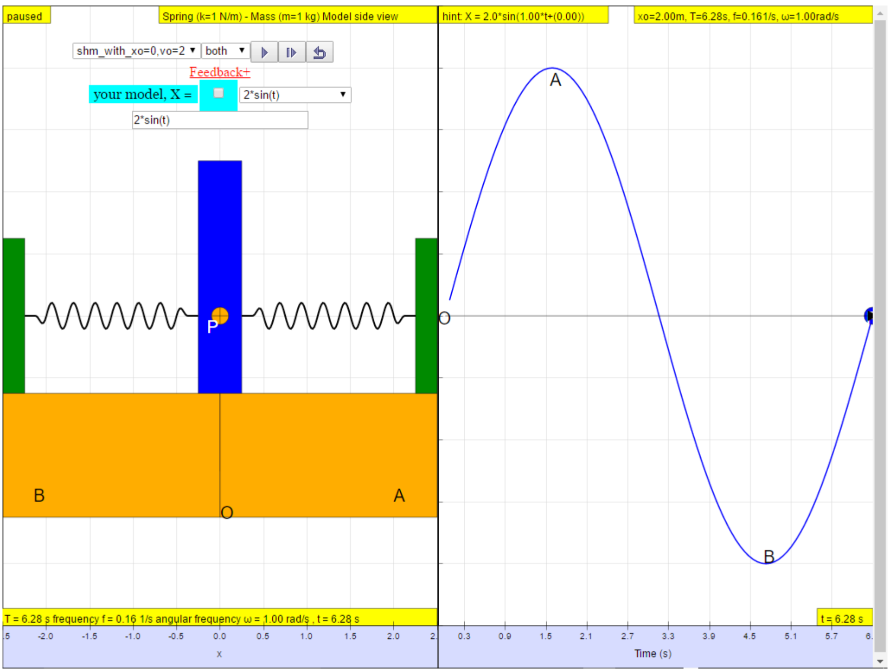

Fig. 1. Horizontal Spring Mass Model with a simple world view layout on the left with only one other scientific view of displacement, x versus time, t graph.

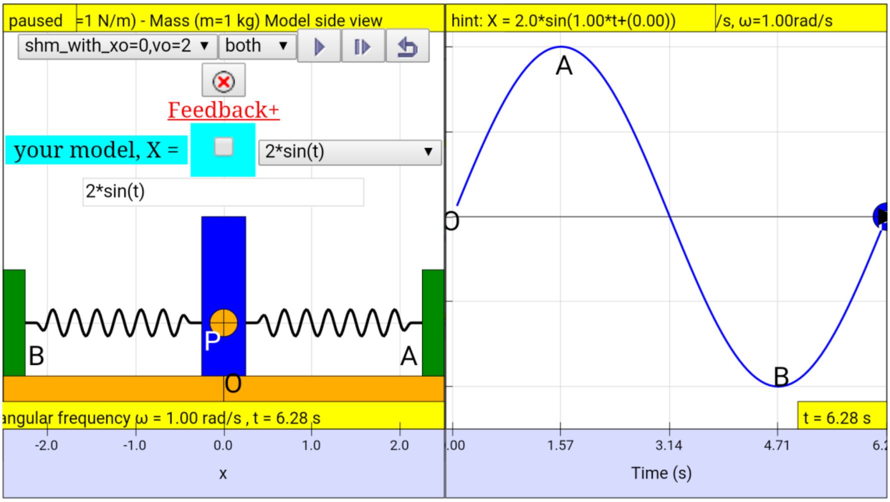

Fig. 2. Same Horizontal Spring Mass Model as in figure 1 showing full screen app-like capability, running on the Android Chrome Browser in a Samsung Galaxy Note 3, 5.5 inch screen size diagonally, in the portrait orientation showing with a simple world view layout on the left with only one other scientific view of displacement, x versus time, t graph.

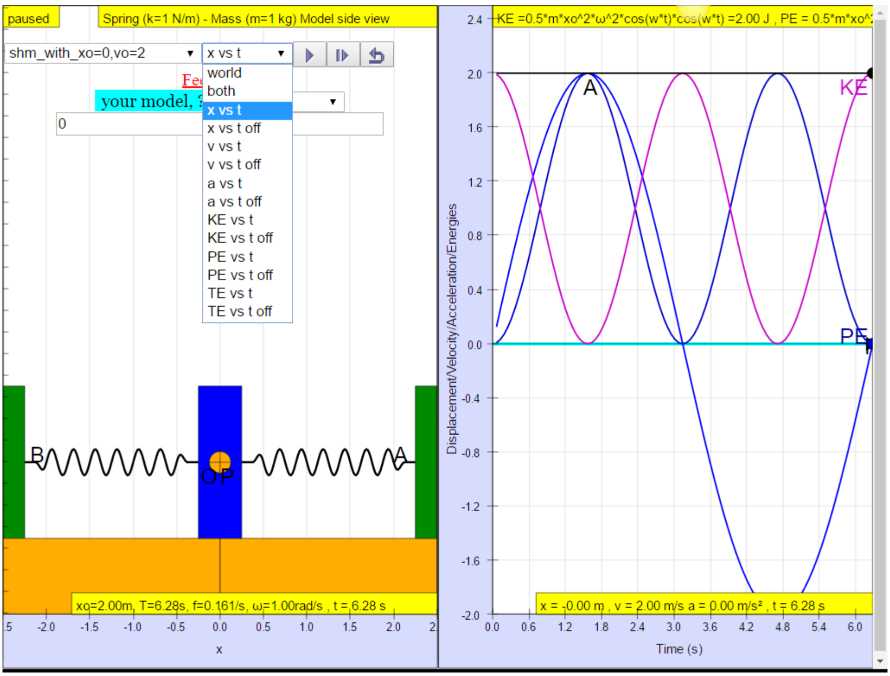

Fig. 3. Horizontal Spring-Mass Model showing a simple world view layout on the left with only one other scientific view of kinetic energy KE, potential energy PE, and total energy TE versus time t, with earlier concepts such as displacement x, versus time, t, velocity v, versus time, t and acceleration a, versus time, t graph. Note that only KE and TE are selected with x versus t.

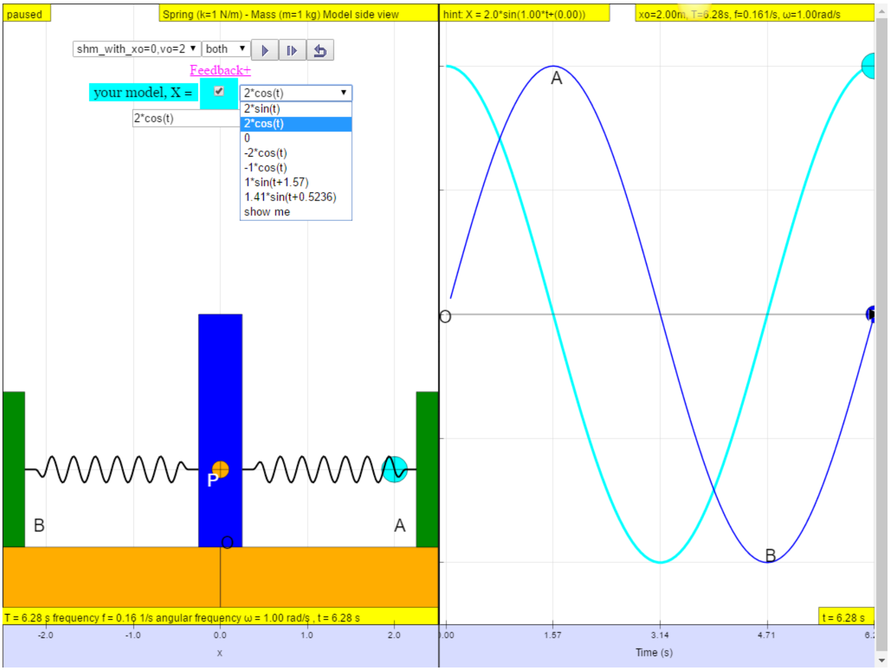

Fig. 4. Horizontal Spring Mass Model with a simple world view layout on the left with only one other scientific view of displacement, x versus time, t graph. Note that student proposed model is selectable via a drop-down menu with some supporting mathematical syntax and a “show me” which determines the generalised form for the motion.

3.2 Teacher design: Gradual buildup of concepts

As teachers using the simulations in the electronic text will want to teach in a more comprehensive manner, connecting earlier concepts to new build-up concepts like kinetic, potential and total energies is needed. Figure 3 shows an oscillating spring-mass system; having the ability to show earlier concepts such as displacement, velocity and accelerations.

3.3 Pedagogical design: progressive mathematical modeling

In view of the phenomenal success of Tracker in allowing students and teachers to represent their understanding of physics through video modeling, I implemented the same kinematic mathematical modeling capability in EjsS models. This was a new approach in teaching and learning with simulations, not implemented in other EjsS and non-EjsS simulations found on the internet. This newly developed progressive mathematical modelling approach in EjsS allows students to propose an initial model where the closeness of fit between simulated data and proposed model suggests an understanding of theoretical application. That is to say, the student may suggest X = 2*cos(t) as an initial model and the simulations immediately draw the plot versus time as a prediction (Radovanović & Sliško, 2013). Clicking the play button then allows the simulations to run as designed for observation. Finally, the apparent mismatch or closeness of fit between model and simulated data can facilitate explanation and discussions. Finally, a “show me” dropdown menu option that displays X = 2*sin(1.00*t+(0.00)) as a generalized solution, is selectable from the drop-down menu, that I believe may help teachers carry out this newly developed progressive mathematical modeling approach in EjsS.

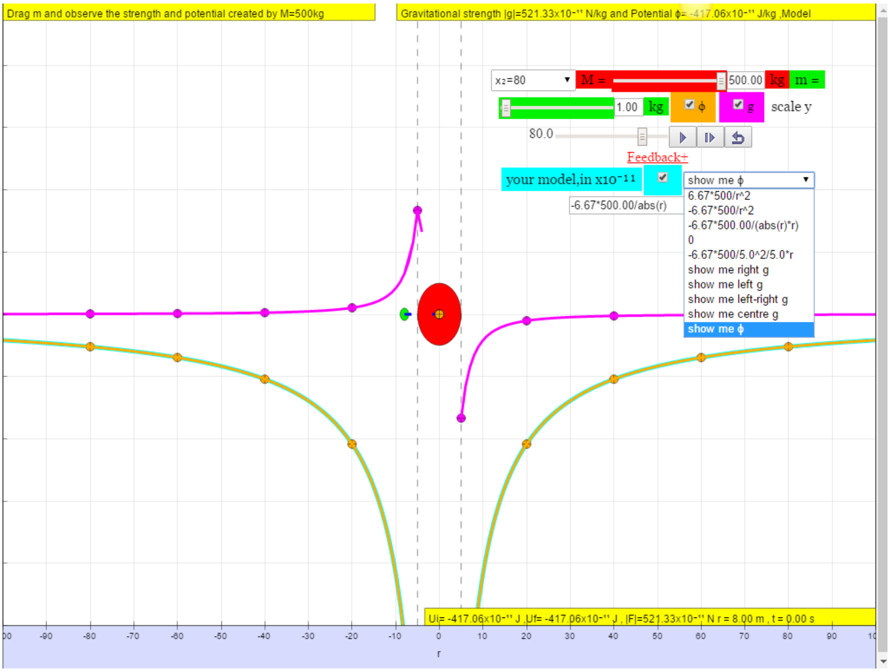

Fig. 5. Gravitational Acceleration and Potential Model with a RED mass M=500 kg creating a gravitational field with a test GREEN mass, m=1 kg, where the field strength g and potential ϕ are simulated. Students then proposed their own initial TEAL model to test if their model matches the theoretical formulae using g = -6.67*500.00/r^2 or ϕ = -6.67*500.00/abs(r) from the drop down menu.

In the chapter on gravitational acceleration and potential, similar designs are implemented where students can propose their own model in —for example g = -6.67*500.00/ r^2 and ϕ = -6.67*500.00/abs(r) as the gravitational field strength and potential. This can then be plotted in teal alongside the theoretical formula for a gravitational mass M = 500 kg and a gravitational constant G of x10^-11 Nm^2/kg^2. Again our initial research findings with fifteen grade 11 students in a mainstream junior college setting suggests that this approach can show the meaning of the Red mass M= 500 kg. The fact that this mass creates the gravitational field and potential was previously not clearly understood when explained with paper representations in the lecture notes.

4 Conclusion

With just these three computer tools (Ejss Modeling Tool, BlueGriffon xhtml editor and Mathtowebonline MathML equation editor) it is possible to create epub3 format electronic books-chapters for computers and tablets that can be published as Apple iBook (Gravity[1], Oscillator[2]), Android Play Book (Gravity[3], Oscillator[4]), and Kindle Book.

1 https://itunes.apple.com/us/book/gravity-advanced-level-gce/id1001442379?mt=11

2 https://itunes.apple.com/us/book/simple-harmonic-motion/id967139041?mt=11

3 https://play.google.com/store/books/details/Loo_Kang_Lawrence_Wee_Gravity_Advanced_Level_Physi?id=LS3_CQAAQBAJ

4 https://play.google.com/store/books/details/Loo_Kang_Lawrence_Wee_Simple_Harmonic_Motion?id=lqGiBgAAQBAJ

Three simulation design principles for electronic book-chapters were discussed above: *3.1 user design: simple & optimum view of screen, 3.2 teaching design: gradual buildup of concepts*, and finally, the most significant point, *3.3 pedagogical designs: progressive mathematical modeling.* I hope to have inspired more educators to create interactive and open educational resources for the benefit of all.

Acknowledgement

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5 http://www.unesco.org/new/en/media-services/single-view/news/the_2015_unesco_king_hamad_bin_isa_al_khalifa_prize_for_the_use_of_icts_in_education_rewards_projects_from_costa_rica_and_singapore/

6 http://edulab.moe.edu.sg/edulab-programmes/existing-projects/nrf2015-edu001-el021

Why Point Particles Lead to a Dead End: A New Visualization Scheme for Magnetism Based on Quantum States

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Magnetism constitutes a fundamental topic of physics education from elementary school up to the university level. To explain ferromagnetic phenomena, practical experiments and phenomenological descriptions currently exist. However, these explanatory approaches show serious deficiencies in describing the nature of ferromagnetism. For example, it is know that point particles cannot serve as an appropriate starting point since the Bohr-van Leeuwen theorem states that all kinds of magnetism vanish according to classical statistical mechanics.
In order to develop an alternative, self-consistent approach, an alternative using quantum states instead of point particles will be shown. Furthermore, our contribution reveals how diamagnetism and paramagnetism can help to illustrate ferromagnetic phenomena following an explanation based on quantum physics. Furthermore, the article describes the development of a short film being used to motivate these typically overlooked magnetic phenomena.

1 Introduction and Motivation

Many technological applications of our modern world are based on magnetic phenomena. Since magnetism has historically been important for mankind (for example, using compasses to navigate or electric motors to improve and build various machines), this topic is relevant at different levels of physics education from basic to higher education. Furthermore, magnetism represents an important subject for current scientific research. This research includes storage devices (Comesaña-Hermo et al., 2012; Neb et al., 2012), medical applications (Nacev, Beni, Bruno & Shapiro, 2011), display technologies (Yin et al., 2011) and magnetic sensing of animals (Begall, Malkemper, Červený, Němec & Burda, 2012).

Unfortunately, a range of studies within physics education research detects poor conceptual knowledge among students from elementary school (Barrow, 1987; Kopp & Martschinke, 2010) to middle and high school (Erickson, 1994) up to the university level (Maloney, O'Kuma, Hieggelke & Heuvelen, 2001; Pollock, 2009) and reveals myriad mental models and representations of magnetism (Tarciso Borges, Tecnico & Gilbert, 1998; Sederberg, Latvala, Lindell, Bryan & Viiri, 2010). Comparing these different investigations, we determined two central issues causing poor conceptual understanding of magnetism.

At first glance, each of the existing models is able to describe and structure magnetic phenomena in a certain area. For example, the model of atomic bar magnets seems to be useful for introductory lessons on magnetism in elementary or middle school. However, most of the existing models are not applicable at different levels of complexity and often generate misconceptions among students about certain issues. These must later be revisited (Tarciso Borges et al., 1998; Sederberg et al., 2010) because the established models at school are operating with classical point particles. Section 2 reveals why this assumption leads to a dead end and presents a new scheme to describe and explain the typical behav-

Laumann, D. & Heusler, S. (2016). Why Point Particles Lead to a Dead End: A New Visualization Scheme for Magnetism Based on Quantum States. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 61–67). European Physical Society.

ior of diamagnetic, paramagnetic and ferromagnetic matter on a microscopic level based on quantum state interpretations.

The term “magnetism” is often used synonymously with “ferromagnetism” in schools, universities, and everyday life. This typical usage of “magnetism” obscures the fact that other types of magnetism, besides ferromagnetism, also exist. While ferromagnetic matter is strongly attracted to magnetic fields, the attraction of paramagnetic objects to magnetic fields is much weaker. Diamagnetic substances, on the other hand, are weakly repelled by magnetic fields. In the periodic table of the elements the magnetic properties of eighty-eight different elements have been measured. Only three of these elements exhibit ferromagnetism at standard temperature and pressure (STP), while thirty-four are diamagnetic and fifty-one are paramagnetic in their natural state (Lide, 2005). One can find various reasons to include diamagnetism and paramagnetism in addition to ferromagnetism in physics education curricula. For one thing, plenty of useful experiments exist that help to demonstrate the magnetic properties of substances being typically classified as “non-magnetic” such as water, or graphite (Simon, Heflinger & Geim, 2001; Daffron, 2009; Chen & Dahlberg, 2011). Diamagnetism and paramagnetism are also seen in several applications - for example: paramagnetic effects enable electron paramagnetic resonance (EPR) and nuclear magnetic resonance (NMR), used for medical diagnostics (Weil & Bolton, 2007; Hore 2015). Likewise, diamagnetic anisotropies are fundamental to liquid crystal displays (Schadt, 1997) and diamagnetism is strongly linked to superconductivity (Tinkham, 1996). First and foremost in this context, however, diamagnetism and paramagnetism is essential to the explanation of ferromagnetism presented in section 2 and 3.

2 A New Visualization Scheme for Magnetism Based on Quantum States

It is important to emphasize at the outset that our quantum based-approach focuses on explanations for magnetic phenomena at the microscopic level. Any introductory unit on magnetism should focus on structured observations of real phenomena being experienced in different experiments or, alternatively, establishing macroscopic models using the magnetization of an object. Any macroscopic treatment of magnetic phenomena can be applied without referring to the microscopic level. Nevertheless, at least at the university level it is necessary to provide microscopic explanations that extend up to macroscopic descriptions of observable phenomena.

In addition to phenomenological approaches that cover macroscopic effects, different types of magnetism need to be understood on a microscopic level. To comprehend various observations, semiclassical approaches are available to calculate the alignment and formation of magnetic moments within an external magnetic field. This leads to similar results compared to much more sophisticated approaches based on quantum mechanics (Langevin, 1905; Feynman, Leighton & Sands, 1964).

Unfortunately, no matter how useful these semiclassical approaches are in illuminating different magnetic phenomena, the Bohr-van Leeuwen theorem states that all kinds of magnetism vanish with consistent application of classical statistical mechanics (Bohr, 1911, as cited in Rosenfeld, Nielsen & Rud, 1972; Van Leeuwen, 1921).

To discuss the origin of different types of magnetism it is essential to consider two approximations being derived from different calculations related to magnetic moments. First, we approximate that only electrons carry magnetic moments to explain the diamagnetic, paramagnetic or ferromagnetic properties of matter. Moreover, we approximate it is reasonable to associate paramagnetism with spin magnetic moments, whereas diamagnetism is associated with orbital magnetic moments caused by a phase shift of the atomic orbitals in an external magnetic field resulting in microscopic currents (fig. 1). Furthermore, magnetic properties of atomically bound electrons, e.g. diamagnetism of nitrogen and paramagnetism of oxygen, must be separated from those of nearly-free electrons as in, e.g., aluminum or iron. The following discussion focuses on the magnetism of bound electrons, but all explanations can be expanded to the magnetism of nearly-free electrons in the con-

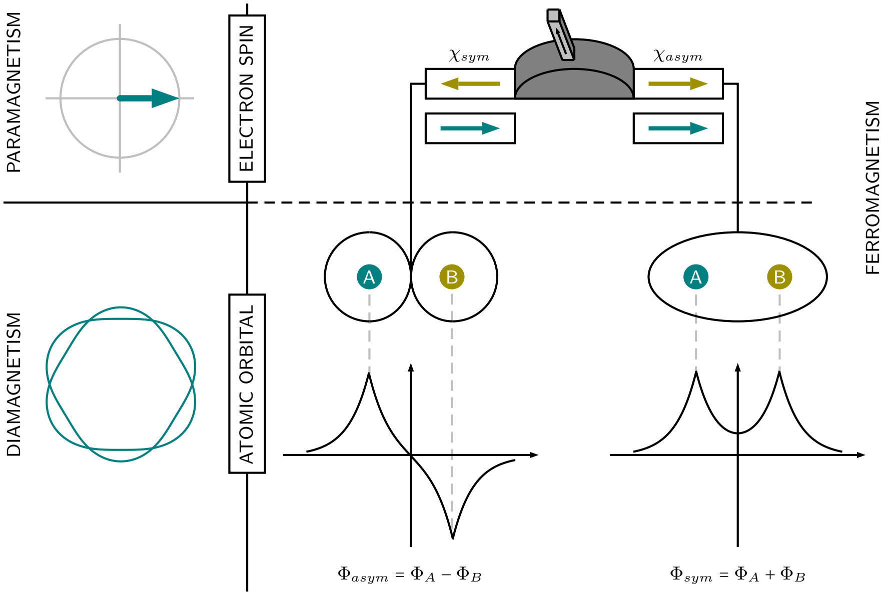

Fig. 1. Visualization scheme for magnetism based on quantum states referring to diamagnetism, paramagnetism and ferromagnetism separating spin and atomic orbital phenomena.

duction and valence bands of solids.

Since a classical point particle does not exhibit a phase, atomic diamagnetism can only be understood in the context of the electron's atomic orbital - specifically, the quantum state. Furthermore, due to the fact that no classical interpretation of the spin is known (Pauli, 1984), it can be inferred that no classical or semiclassical approach can explain paramagnetic phenomena on a microscopic level. Consequently, it seems useful to employ visualizations explaining magnetism based on quantum physical formalisms. These visualizations can help to illustrate invisible processes and potentially reduce the complexity of quantum physical formalisms (Zollman, Sanjay Rebello & Hogg, 2002; McKagan et al., 2008; Kohnle et al., 2012).

Our visualization scheme illustrates atomic paramagnetism using a typical pictorial representation of the electron spin (fig. 1, top left) and atomic diamagnetism using atomic orbitals (fig. 1, bottom left) along with their behavior within external magnetic fields. From these visualizations, more sophisticated explanations and descriptions can be performed on a microscopic level. Since it is not the main focus of this article, further theoretical considerations are omitted. A major benefit of our visualization scheme is that ferromagnetism (being the most recognized type of magnetism) can be explained on the microscopic level based on quantum states as well.

As already mentioned, paramagnetism and ferromagnetism can be distinguished by their response to an external magnetic field. In the absence of a magnetic field, paramagnetic objects lose their magnetization entirely, while ferromagnetic matter (potentially) remains magnetized. To understand this process we should reduce the problem to two magnetic spin moments related to the electrons A and B (fig. 1, right). Within an external magnetic field all magnetic moments are approximately aligned parallel to the external magnetic field. If we remove the external magnetic field, the paramagnetic moments align antiparallel, cancelling each other out while the ferromagnetic moments, potentially, remain parallel. How can this be explained?

The reason is that paramagnetism and diamagnetism are phenomena of single electrons

Fig. 2. Phenomenology of diamagnetism, paramagnetism and ferromagnetism visualized in the project teaser *"Magnetismus hoch 4"*.

while ferromagnetism refers to interacting electrons. This means that without a magnetic field, paramagnetic moments are randomly aligned without respect to their neighbors. Conversely, the exchange interaction of two ferromagnetic moments keeps their alignment parallel. Two interacting electrons follow the Pauli principle. From this it follows that the total wave function of both electrons as the product of their spatial wave function and spin wave function must be antisymmetric. Since parallel aligned spins reveal a symmetric spin wave function, the corresponding spatial wave function must be antisymmetric (fig. 1). "Switching" one spin instantly, with the spin wave function antisymmetric, causes the electrons to relocate according to a symmetric spatial wave function. Since the relocation of electrons requires (Coulombic) energy, it is often energetically more favorable to conserve parallel aligned spins resulting in a ferromagnetic magnetization (fig. 1). Compared to a light switch, the majority of the energy is not needed to flip the switch but for the consequences, e.g., the heating of the filament. In case of ferromagnetism the majority of the energy is related to the relocation of electrons, instead of the spin flip itself.

The complexity of ferromagnetism can be reduced using visual representations initially leaving out further formalism and calculations. Furthermore, it is essential to be familiar with electron spins and atomic orbitals to understand ferromagnetic phenomena. We can see that the electron spin corresponds to paramagnetism while magnetic moments of atomic orbitals give rise to diamagnetism. Thus, gaining insight into diamagnetism and paramagnetism can aid comprehension of ferromagnetism. This interpretation of these three types of magnetism and their respective relationship is a key feature of our work at the university level. It also adds to the phenomenological treatment and macroscopic modeling of magnetism at lower levels of education.

3 Living in an Entire Magnetic World – A Motivational Short Film

Since section 1 and 2 emphasize the importance of diamagnetism and paramagnetism in understanding ferromagnetism and in wider understanding of magnetism in general, it is necessary to provide access to education on these types of magnetism. It seems useful to establish different experiments to investigate the typical features of diamagnetism and paramagnetism that give rise to observable phenomena (Simon et al., 2001; Daffron, 2009; Chen and Dahlberg, 2011). These experiments, and others being developed in our work,

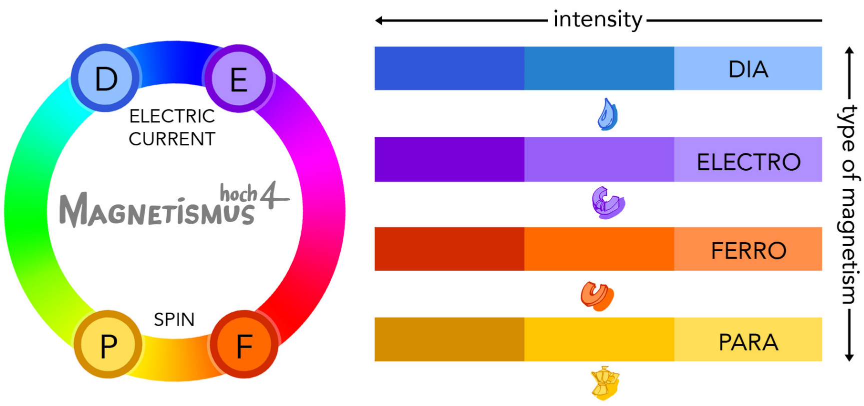

Fig. 3. Color code to visualize the type and intensity of magnetism of an object within "*Magnetismus hoch 4*".

can help to demonstrate that many objects interact with magnetic fields. Even these experiments can not demonstrate that we are actually living in an entire magnetic world where practically every object is attracted or repelled by a magnetic field, since the strength of the interaction is often very weak.

Again, visualizations can be used to express these ideas and enable thought experiments on magnetism that are impossible to realize. In the project *Magnetismus hoch 4,* German for Magnetismus[4], we try to develop various multimedia content related to magnetism. The content targets physics students at an introductory university level. Initially, we developed a project teaser in the form of a short film. The teaser aims to motivate students to deal with different types of magnetism, their phenomena, and nature and prompts questions that should be discussed later on (fig. 2). The title *Magnetismus hoch 4* refers to the most relevant types of magnetism, namely diamagnetism, paramagnetism, ferromagnetism and finally electromagnetism.

Considering these types of magnetism, it is important to be aware that diamagnetism, paramagnetism and ferromagnetism represent magnetic material properties, while electromagnetism refers to the electric conductivity of a substance. From this point of view electromagnetism should be separated from the other types of magnetism. Nevertheless, there are several connecting aspects. First, diamagnetism and electromagnetism are both related to either microscopic or macroscopic electric currents and, therefore, share their physical source. Second, it is important to convey the idea that each substance can show electromagnetic phenomena independently from the underlying magnetic material properties. Conclusively, the typical treatment of magnetism in school and university education has a focus on ferromagnetism and electromagnetism. Since the project *Magnetismus hoch 4* tries to provide a comprising concept to teach all types of magnetism, it seems necessary to consider electromagnetism next to diamagnetism, paramagnetism and ferromagnetism. Thereby, the special character of electromagnetism will be emphasized in the teaching materials.

The teaser tells the story of a scientist who investigates the consequences of an extremely strengthened magnetic field in the earth. Such a situation would create unexpected magnetic phenomena. The story of the teaser is similar to a typical thought experiment. Furthermore, we use a narrative structure supporting different topics related to magnetism. The teaser can initiate discussions on electromagnetism, the earth's magnetic field, the nature and behavior of diamagnetic, paramagnetic and ferromagnetic objects, diamagnetic levitation, the various orders of magnitudes of magnetic fields and thought experiments in general (fig. 2).

An example for one concept of our teaser that will be continued in all multimedia content within the project is a color code emphasizing the magnetic properties and state in a given situation (fig. 3). We chose different colors for each type of magnetism. Since either microscopic or macroscopic electrical currents cause diamagnetism and electromagnetism, whereas paramagnetism and ferromagnetism result from spin magnetic moments, each of these pairs shares closely related colors on the color circle (fig. 3). Additionally, the color intensity indicates the strength and intensity of the magnetic properties. Furthermore, the background of all scenes within the teaser is illustrated in different shades of gray to strengthen the effect of the color code.

4 Conclusions and Outlook

We are developing a self-consistent model for magnetism that can be extended in complexity from elementary school to high school and finally university level. We follow a top-down design-based research approach to ensure the applicability at different levels of complexity. Thus, it is necessary to develop a self-consistent model providing explanations for all major kinds of magnetism at the university level, which is the focus of the present contribution. Subsequently we need practical experiences and empirical studies to see how our materials influence students' conceptual understanding of magnetism. Thereafter, the model needs to be adjusted for lower levels of education. When teaching physics in schools, it is sufficient to limit visualizations and emphasize phenomenological approaches. At the university level, the model and visualization scheme should support student's comprehension of mathematical formalism on quantum theory. Finally, we are still developing further multimedia content to make our ideas accessible for lectures or courses.

Acknowledgement

The project teaser *Magnetismus hoch 4* has been developed in cooperation with the professional illustrator Matthias Ries. He is responsible for the design concept of our materials and developed the storytelling principle together with Daniel Laumann. Furthermore Lukas von Berg (character animation), Pascal Brinkmann (sounds) and Helge Salnikau (speaker) contributed their work and helped us to realize this short film. The teaser including English subtitles and more content related to the project *Magnetismus hoch 4* is available on www.magnetismushoch4.de.

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VIRTUAL AND REMOTE LABS IN PRACTICE

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

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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 metafunctionality 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 is 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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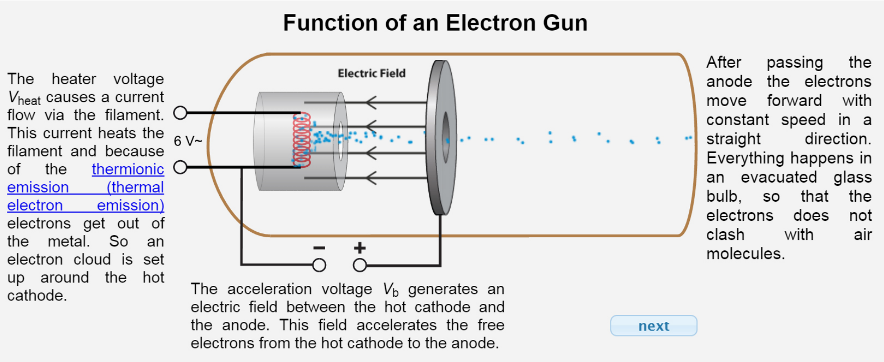


Fig. 1. Function of an electron gun described above (in the environment, electrons are animated).

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, Ganoe, 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.

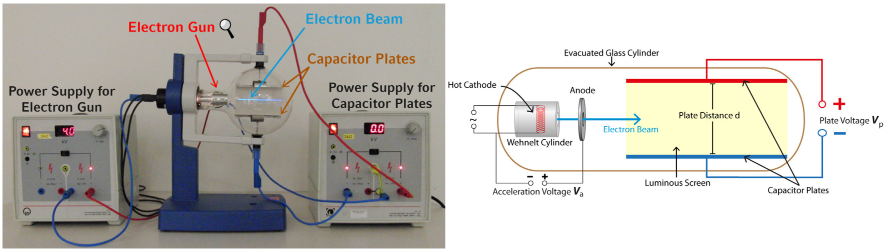


Fig. 2. Experimental setup with a picture of the experiment and a schematic diagram.

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.

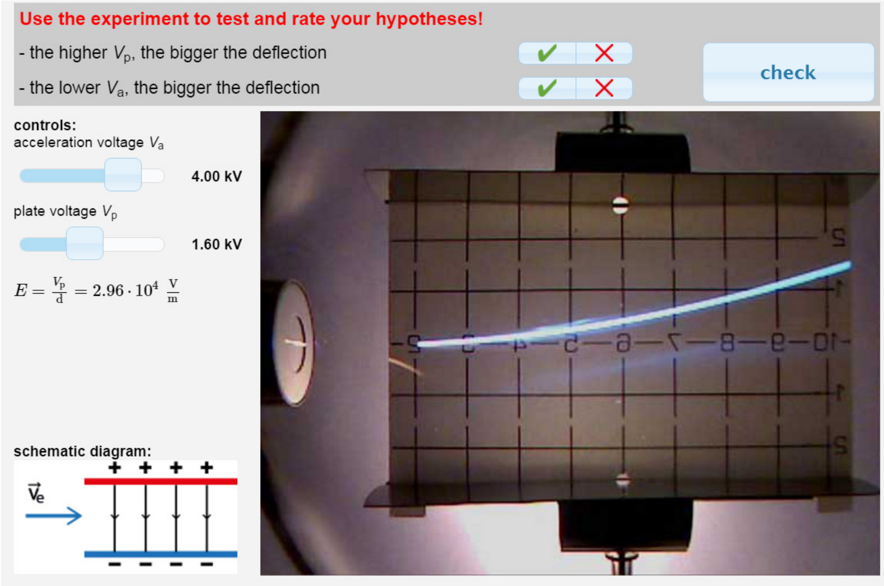


Fig. 3. Testing and rating the chosen hypotheses with the virtual experiment.

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

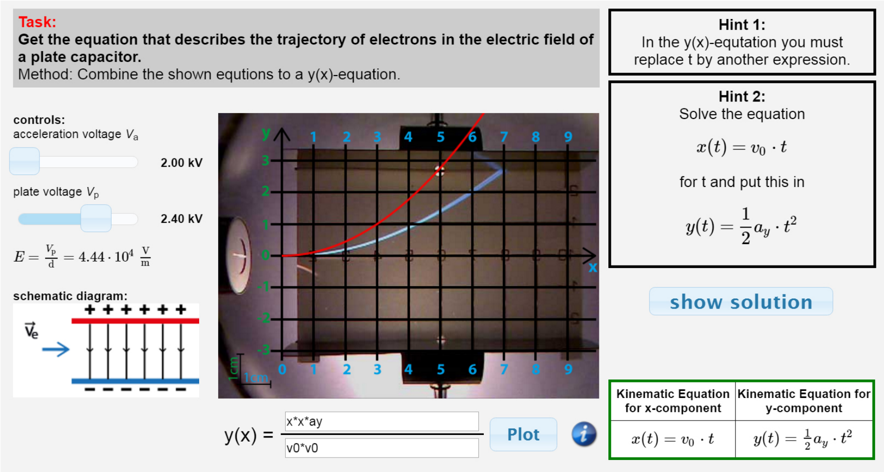


Fig. 4. Generating a function using the kinematic equations and substitution with hints displayed.

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).

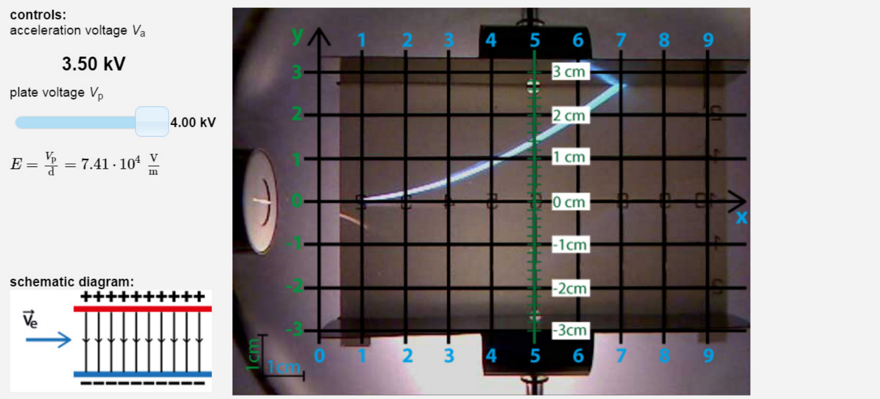
Likewise, the inverse proportionality between acceleration voltage and deflection y(x) must be shown likewise. Based on these insights, learners have to create a mathematical description of the electron trajectory. Formula modules support this step and the plot of the chosen function over the picture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



capacitor voltage	0,8 kV	1,6 kV	2,4 kV	3,2 kV	4,0 kV
deflection on x = 5 cm	0.3 cm	0.5 cm	0.8 cm	1 cm	1 cm
$\frac{\text{deflection on x} = 5\text{ cm}}{\text{capacitor voltage } V_p}$ in $\frac{\text{cm}}{\text{kV}}$	0.375	0.313	0.333	0.313	0.250

check

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

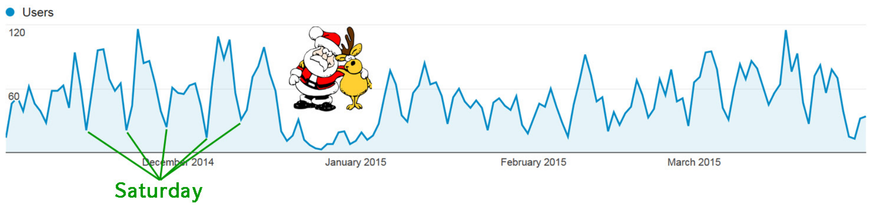


Fig. 6. Distinct users per day between November 1st 2014 and March 31st 2015.

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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UNED, Madrid, Spain

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 online 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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 87–93). European Physical Society.

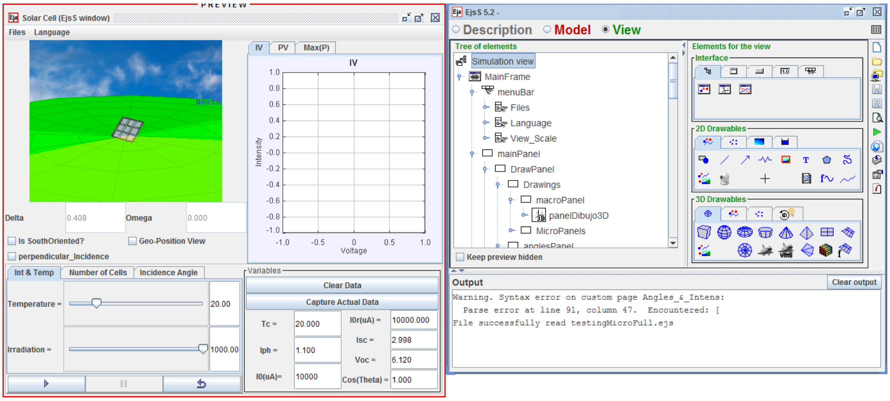

Fig. 1. Main view of the EjsS editor. The View tab contains the GUI editor defined by a tree structure of graphical elements from the right panel.

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 beahvior 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,

$$I = I_{\mathrm{ph}} \cdot \cos\theta - I_0 \cdot \left[e^{\left(\frac{q(V_c + I \cdot R_S)}{mkT_c}\right)} - 1 \right] - \frac{(V_c + I \cdot R_S)}{R_{\mathrm{sh}}} \qquad \text{(Eq.1)}$$

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-

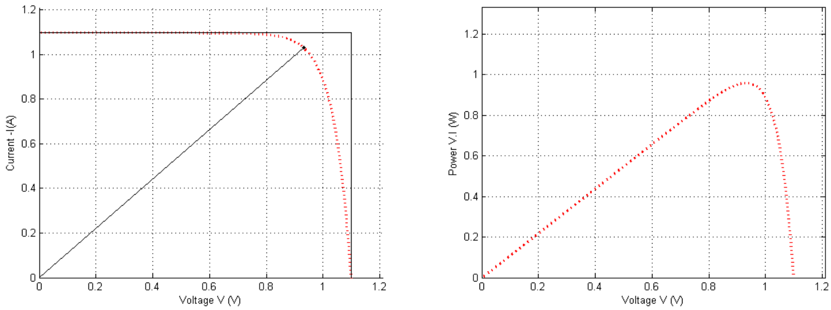

Fig. 2. Left. Characteristic *I-V* curve of a solar cell, contains information about the cell behavior, like the short circuit current, open circuit voltage and maximum power point (Mpp). Right. Characteristic *P-V* curve of a solar cell.

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 = 1m/s, ambient temperature of T_a = 20ºC, and hemispherical irradiance G = 800 W/m^2.

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

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.

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

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

$$I \quad = \left[\frac{I_{scr}}{e^{\left(\frac{qV_{ocr}}{mN_skT_c}\right)}}\right]$$

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/m^2) 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.

$$I_{\mathrm{sc}} = [I_{\mathrm{scr}} + K_{\mathrm{i}} \cdot (T_{\mathrm{c}} - T_{\mathrm{r}})] \cdot \left(\frac{G}{G_{\mathrm{r}}}\right) \qquad \text{(Eq.5)}$$

$$V_{\mathrm{oc}} = [V_{\mathrm{ocr}} + K_{\mathrm{v}} \cdot (T_{\mathrm{c}} - T_{\mathrm{r}})] \qquad \text{(Eq.6)}$$

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.

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

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.

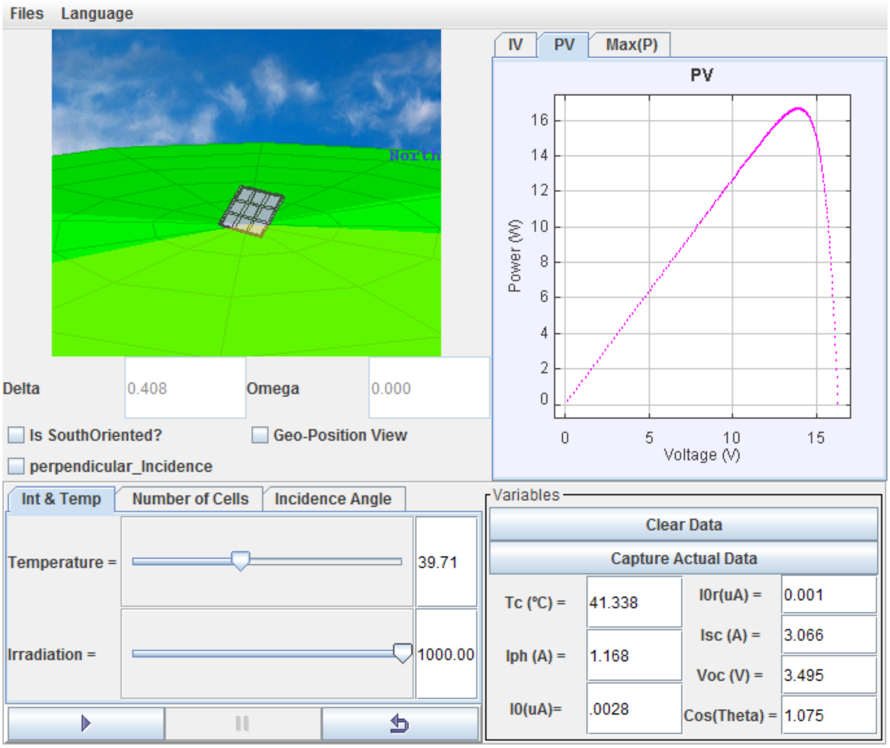

Fig. 3. Three sections, menu, system representation and evolution graphs of the main view of the user application.

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 irradiations, 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.

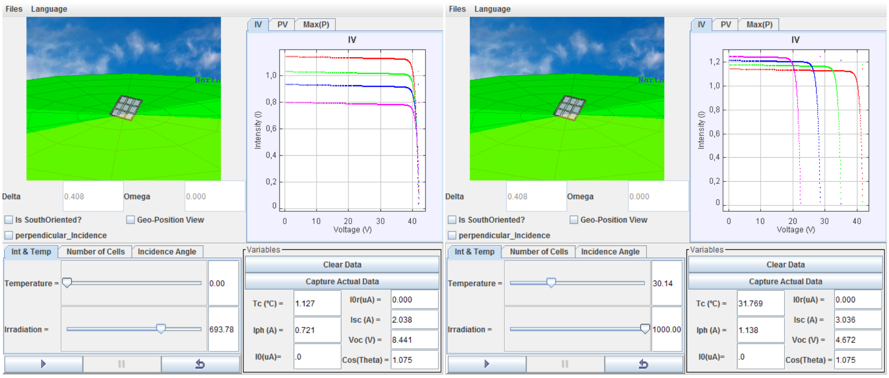

Fig. 4. Left. Curves for a decreasing irradiance. Right. Curves for a increasing ambient temperature.

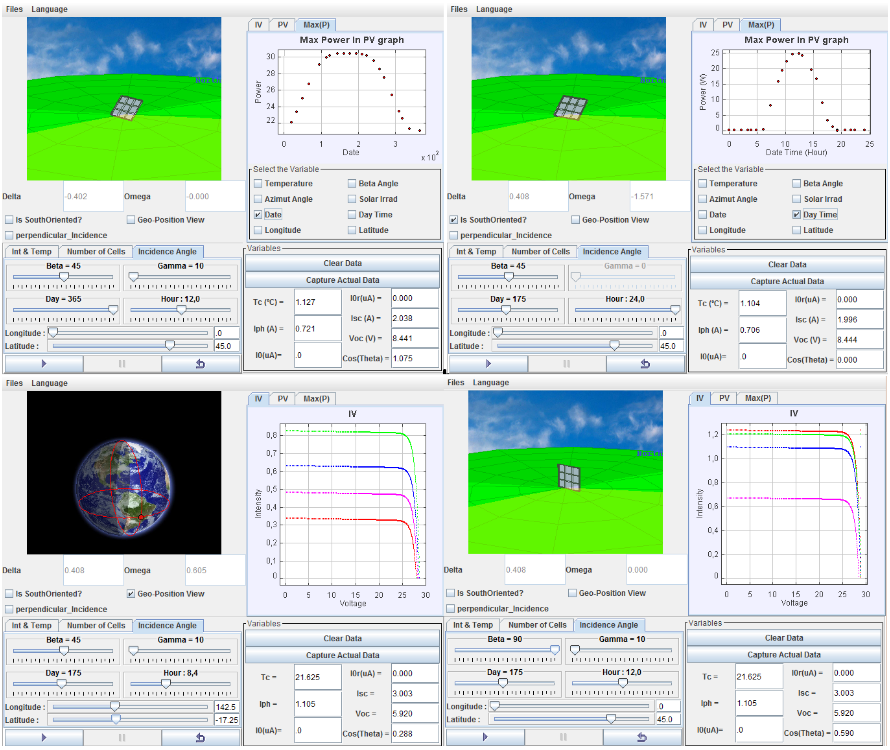

Fig. 5. Upper-Left. Maximum power for the different days in a year at 12h. Upper- Right. Maximum power obtained from the solar panel during the day. Bottom-Left. Changing latitude to obtain the characteristic curves. Bottom-Right. Changing inclination to obtain the characteristic curves.

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.

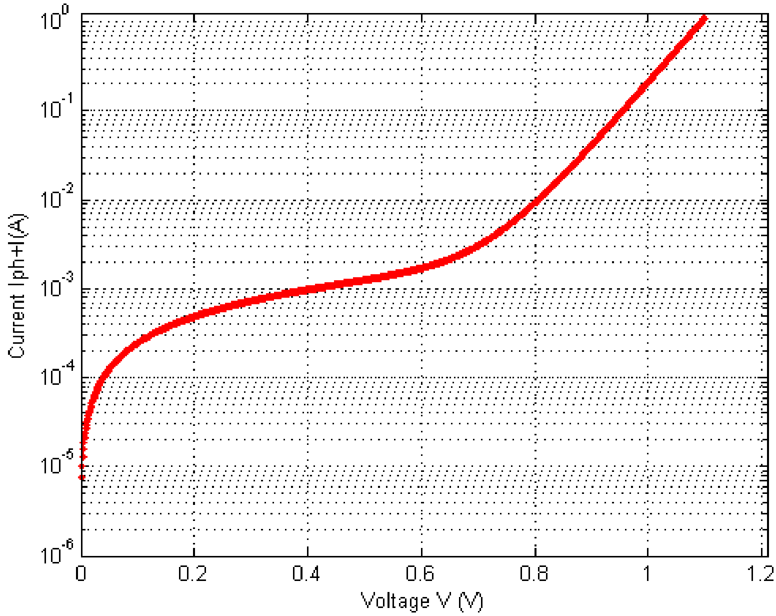

Fig. 6. Voltage and intensity in a semi-logarithmic plot.

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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Performing Automated Experiments With EjsS Laboratories

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Current software allows for the development of high quality interactive applications that are transferable to laboratories, both virtual and remote. To perform an experiment, the user needs to know how these applications are implemented. In addition, when coding an experiment, the user must manage the language in which the simulation was created and demonstrate fluent use of the simulation language just to perform experiments. In the academic field these simulations are used to create virtual and remote laboratories. The authors propose a tool to develop automated experiments for these laboratories. A new environment for the development of experiments for simulations developed with the authoring tool Easy java (script) Simulations (EjsS) is proposed. It permits decoupling of the application design phase from the experiment design. It is equipped with a new language encompassing all the desired commands, such as creating events, launching simultaneous applications and modifying their variables. Designed as a high level language, it allows less experienced users to create their own experiments without any knowledge of how the application was made. It maintains a balance between simplicity and functionality. These features will be explained throughout this article and the use of some Physics and Control Systems examples of use will be given to demonstrate the potential of this new environment.

1 Introduction

The main reason for creating an interactive simulation for a virtual and/or remote laboratory (VRL) is to carry out easily some actions or changes that allow the user to see significant results, that is, to perform experiments with the VRL. A typical definition of experiment is "the process of extracting data from a system by exerting it through its inputs", [1]. This definition needs to be made more general when our experimentation system is a computer simulation.

Consider, for instance, a computer simulation of a tank with a water level Proportional-Integral (PI) controller. A PI controller is a control loop feedback mechanism (controller). It continuously calculates an error value as the difference between a desired setpoint and a measured process variable. The controller attempts to minimize the error over time by adjustment of a control variable to a new value determined by a weighted sum. An experiment for this simulation could consist of the following actions:

1. Set initial conditions.
2. Wait for the simulation to evolve until the initial set point is reached with a certain tolerance.
3. Increase the set point.
4. Let the system evolve until the exact moment when the level reaches the new set point with a certain tolerance.
5. Compute the time elapsed in step 4.
6. Repeat steps 1 through 5 one hundred times with different sets of PI parameters.
7. Conduct an analysis on the results obtained above.

Galan, D., Heradio, R., de la Torre, L., Dormido, S., & Esquembre, F. (2016). Performing Automated Experiments With EjsS Laboratories. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 95–102). European Physical Society.

These actions cannot be executed effortlessly, or in reasonable time by a user interacting with the graphical user interface (GUI). Some actions might be simply impossible without computer help. Instead, it would be preferable if users could count on a flexible experimentation language that allows them to instruct the simulation to automatically run the experiment. This way, the VRL is treated as a complete system in which all variables are observable, and all variables and the VRL application execution itself are controllable.

An experiment could also be used by teachers to automatically process students' work evaluation. For instance, a control problem, [2], with different design requirements could be given to students. They would then be asked to determine the control parameters that meet certain defined goals. Finally, teachers take the proposed control parameters and run a simulation of the control system to check if the design requirements are satisfied.

In order to test the viability of our experimentation language, we have implemented it using the modelling tool Easy java(script) Simulations, (EjsS), [3]; a software tool that helps the user with the creation of interactive simulations in java, [4], or javascript. It has been designed to be used by scientist without special programming skills, and has been proven to simplify the creation of simulations for scientific and engineering purposes [5, 6]. Simulations created with EjsS are complete, standalone applications that can be distributed independently of EjsS. A more detailed description of the Application Programming Interface (API) can be found in Ref [7].

This paper is organized as follows. Section II describes experimental languages used currently as well as the basic requirements for an experimentation language. Section III discusses the implementation of the language using EjsS simulations and the functionality that it adds. Section IV shows some examples that use our experimentation language in practice. Finally, Section V discusses the results and describes further work.

2 Integrated Development Environment

The idea behind VRLs arises from the need for a suitable system that can be used from bachelors to masters' students [8]. The typically have only a basic (high-school level) mathematics background, but their knowledge of control is extremely limited at best and nonexistent in most cases. Masters' students, on the other hand, have a strong mathematics and control engineering background, but, except for experiences carried out at the university laboratory (for example, inverted pendulums, dc motors, magnetic levitation), they have little familiarity with advanced control experiments. For this reason, they are unable to anticipate how systems will react in certain situations. Thus, a qualitative teaching/training system with room for both new users and experts is a useful tool to learn how to manage all scenarios.

For undergraduate students, VRLs are enough to acquire the basic know-how of the system under study. Nevertheless, masters' students require greater difficulty and challenging assignments with VRLs to consolidate advanced concepts that seem, a priori, impossible to grasp with only VRLs.

The Experiment Editor for EjsS simulations was created as a tool for master students in order to improve their experience with VRLs.

2.1 The Experiment Editor

The experiment editor Integrated Development Environment (IDE) is composed of three main elements, as shown in figure 1: The Virtual Laboratory, the Editor and the Data Tool. As it stated in the introduction, the Experiment Editor uses EjsS Vls. These VRLs are compiled and can be run independently, but in this case, the Editor is responsible for opening and interacting with them. The Editor has tabs with all the experiments developed for the current VRL, the experiment code to work with, a log window to see the system and error messages and a set of buttons with different functions (such as opening a new VRLs, adding or removing experiments, saving the environment, open the Data Tool, showing help or information about variables of the laboratories, etc.). Finally, the Data Tool included in the

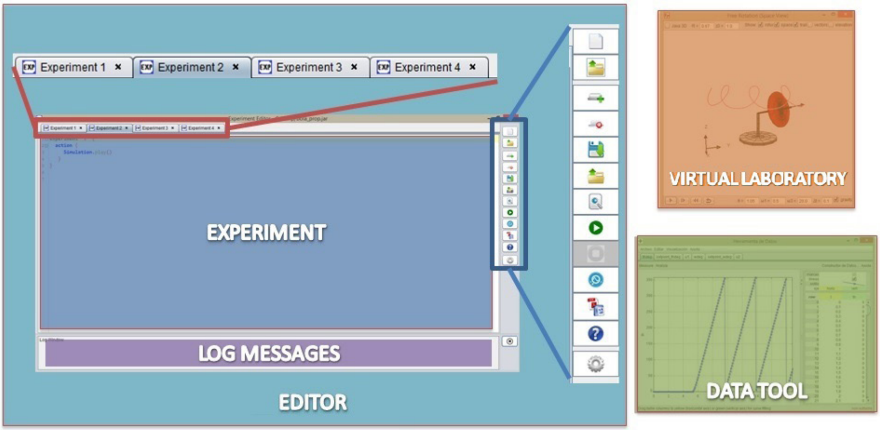

Fig. 1. Elements of the Experiment Editor..

Editor is used to analyze the results of the experiments, trace variables and do statistical studies with these results.

2.2 Experiments language

The most important part of a satisfactory experiment is the language used. The primary objective is to be able to control every aspect of a VRL as if it were a completely observable and controllable component.

The authors submit an interpreted language, as such, the users do not need to recompile VRLs over and over with every change made in an experiment. Instead, they can just run it and see the results immediately. The language allows for interaction with the virtual laboratory, but also, permit the creation of functions, access to text files and the definition of variables, types, loops, and so on. The language is developed for EjsS VRLs (compiled and closed applications) so that the language can interact with their java bytecode. There is an interface created for this so that the laboratory can send data in the experiment language and the experiment language can modify the VRL.

Some of the most important functions created to interact Some of the most important functions created to interact with the VRLs are shown in table 1. Their use can be seen in Examples Section.

Function	Use
play	Plays the virtual laboratory
play_and_waitt	Similar effect to play, delays the execution of code after this instruction until the VRL pauses
pause	Pauses the VRL
step	Advances by one time step
reset	Completely resets the VRL
stop!	Finishes the experiment
create_subordinate	Runs a copy of the VRLs from which the experiment is started

Tab. 3. Main functions of the Experiments language.

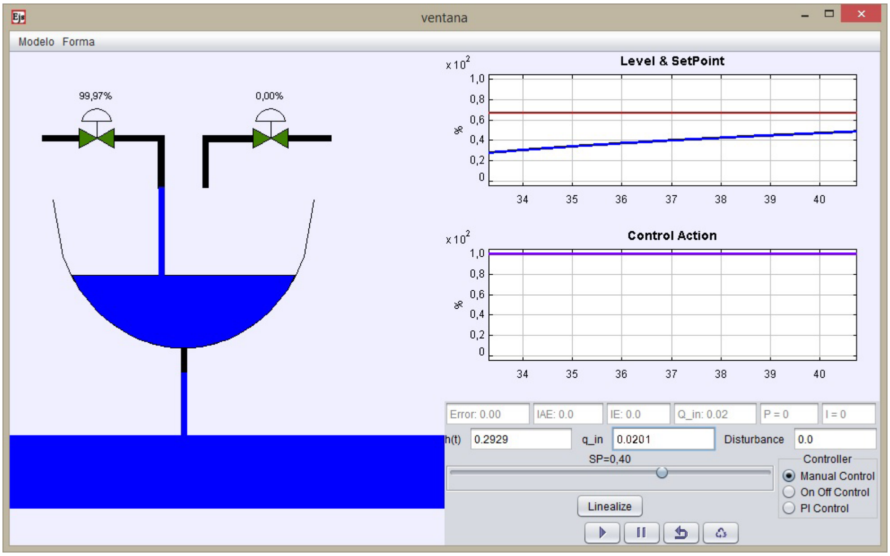

Fig. 2. Water Tank interface.

3 Some Experiments for the Water Tank System

This section presents several examples to show the usefulness of the experiment language and the advantages of using it. Each of these examples contains a brief description of the experiment, the code of the experiment, its results and the advantages of working with the experiment editor. Experiments have been developed for the water tank system VL. The general features and functionality of the experiments are detailed below.

3.1 The Virtual Laboratory

The virtual laboratory was developed using Easy java(script) Simulations (EjsS). EjsS is a freeware, open-source tool developed in Java, specifically designed for the creation of interactive dynamic simulations [9]. EjsS simulations are created by specifying a model to be run by the EjsS engine and by building a view to visualize the system being modelled and to interact with it. The Department of Computer Science and Automation of UNED commonly uses EjsS simulations as a virtual or remote laboratory.

The virtual laboratory interface, shown in figure 2, has a menu bar to choose the shape of the model, and between the lineal and non-lineal model at the top of the window. The graphical representation of the tank, the water level, and the two valves are shown on the left part of the interface. The right part includes two plots, one to visualize the current level of water in the tank (ranging from 0-100% full) along with the set point of the controller, and the other displays how open the water inlet valve is (again, in percentages). Immediately after the plots, there are some non-editable parameters that provide important information to the user about how to configure the possible controllers. Buttons for pausing, playing and resetting the simulation are also present in the lower part of the application.

Two additional dialog windows provide the user with options to vary the control operations. It is possible for the user to choose between a manual control, a PI (Proportional-Integral) /P (Proportional) controller and an On-Off controller; these options are shown at the bottom of the image. When using the PI/P controller mode, the related PI parameters can be adjusted using the PI dialog ("Kp" for the proportional parameter and "Ti" for the integral parameter). Similarly, the On-Off parameters can be set in the On-Off dialog. Choosing either of the controllers, the set points can be established from the slider located at the right part of the window or from the visual representation by arrows shown at the right of the tank (fig. 2).

```
experiment “Different PI controllers” {
 reacts_to “setpoint”
 action {
 subordinate = sim.createSubordinate()
 sim.prepareSubordinate(subordinate)
 subordinate.Kp = 3
 subordinate.Ti = 100
 sim.playAndWait()
 }
}
event “setpoint” {
 action { setSetPoint(40) }
 check { 6-sim.t }
}
```

List. 1. Different PI controllers.

3.2 Experiments

3.2.1 Two PI controllers with different parameters

This experiment is used to compare the responses of the PI control with different “Kp” and “Ti” parameters. A simplistic solution would be to run the simulation by hand twice, once for each couple of parameters, take snapshots of the evolution graphs, and then compare them looking at each graph side by side. A better procedure, however, is to conduct an experiment that automatically creates a second copy of the simulation, changes its parameters, and then runs both simulations simultaneously, displaying the graph of their responses in the same plot. This is what Listing 1, a more elaborate experiment does.

The he output of this experiment is shown in figure 3. Green lines in the plot refer to the second copy of the simulation (Kp = 3, Ti = 100), while the blue and purple lines are from the original simulation with default values (Kp = 1, Ti = 15). The liquid colour of the tank also changes to enable visual comparison between the water levels of the two simulations.

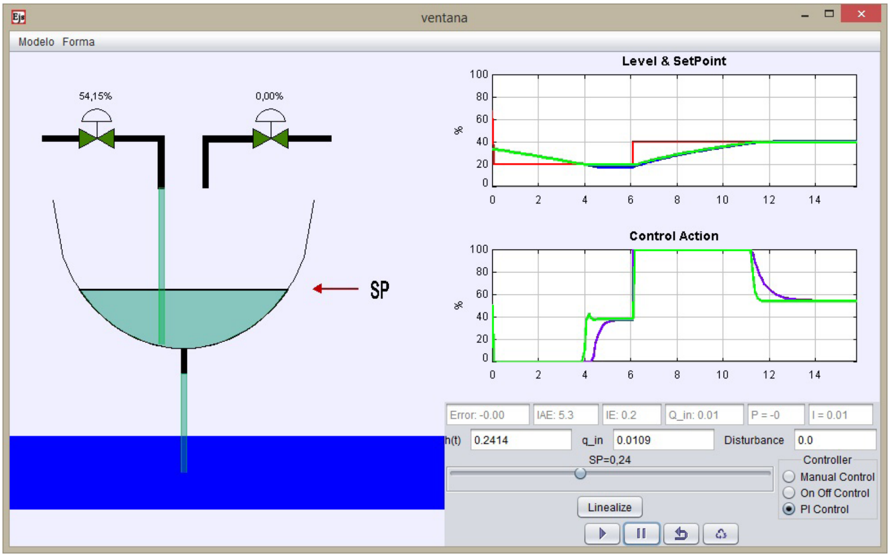

Fig. 3. Water Tank Experiment 1 result.

```
experiment "Auto-tune" {
  reacts_to "manual"
  action {
    sim.experimentOn=true
    sim.setSetPoint(35)
    sim.playAndWait()
    At= At2 - At1
    a = h2 - h1
    sim.kcAT= 4*d/(Math::PI*Math.sqrt(a*a-e*e))
    sim.control = 2
    sim.setSetPoint(51)
    sim.K= 0.45*sim.kcAT
    sim.Ti= At/1.2
    sim._alert("New params Kp:",sim.K,"Ti:,sim.Ti")
    sim.playAndWait()
  }
}
event "manual" {
  action {
    sim.control = 0
    sim.q_in= relepwrOn
    activate "releOn"
  }
  check { 30-sim.t  }
}
condition "releOn" {
  check { (sim.H*50/100-sim.H*5/100)>=sim.h }
  action {
       sim.q_in= relepwrOn
       activate "releOff2"
  }
}      condition "releOff" {
  action {
    At1 = sim.t
    sim.q_in= relepwrOff
    activate "releOff"
  }
  check { (sim.H*50/100+sim.H*5/100)<=sim.h }
}
condition "releOn2" {
  check { ((sim.H*50/100-sim.H*5/100)>=sim.h }
  action {
       h1 = sim.h
       sim.pause()
  }
}
condition "releOff2" {
  action {
       At2 = sim.t
       h2 = sim.h
       sim.q_in= relepwrOff
       activate "releOn2"
  }
  check { (sim.H*50/100+sim.H*5/100)<=sim.h }
}
```

List. 2. Auto-tune experiment.

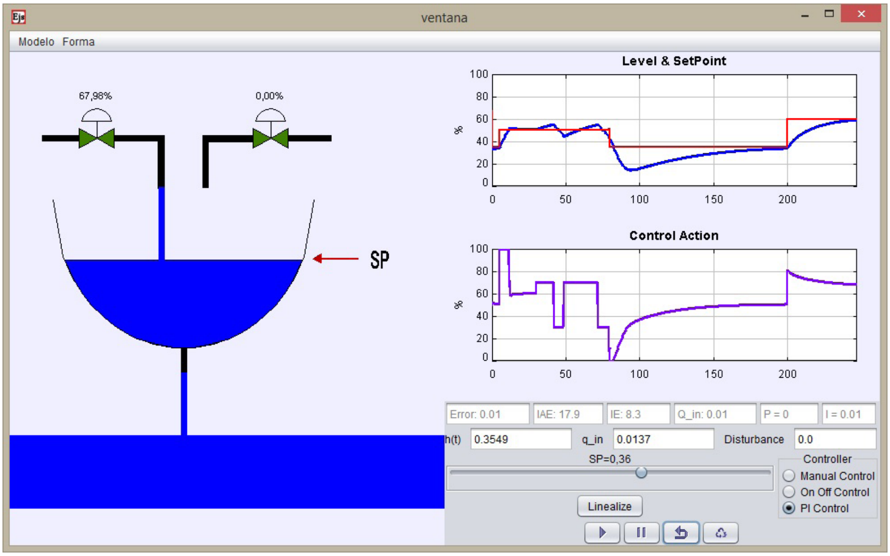

Fig. 4. Water Tank Experiment 3 result.

3.2.2 Auto-tune of a PI controller

An advanced experiment, described in Listing 2, is depicted on figure 4. In this case the experiment uses the water tank controlled by a PI controller to demonstrate the relay tuning method [15], which is based on classical methods proposed in Ref. [10]. The relay tuning method is based on a closed loop estimation. To achieve this method, the following steps must be followed:

- Bring the process to a stationary state.
- Close the loop, using with a relay as the process controller.
- Record output (the controlled variable, in this case, the water level of the tank) until a limit cycle is observed.
- Note the amplitude of the limit cycle as "a" and the period as "tc".
- Determine the critical gain as:

$$Kc = \frac{4d}{\pi\sqrt{a^2 - \varepsilon^2}}$$

The simulation starts with the tuning phase at time = 30 (in the software it is started manually). The amplitude and period of the system response is used to tune the PI controller. After time t = 100, the controller set with the new parameters computed by the tuning method are used to control the system.

Figure 4 shows the simulation when the experiment is completed.

4 Conclusion

To help automate experimental tasks in virtual and remote laboratories, a new language and its corresponding IDE have been presented in this paper. Current alternative approaches to automate experiments require interacting directly with the software that implements the laboratory, and therefore must also use the same language in which the lab is written. In contrast to this, in our approach (i) existing laboratories are automatically wrapped, enabling a clean API to observe and control the laboratory; (ii) experimental tasks are scripted in a language specifically designed to do so. Finally, the IDE we provide supports gathering data from the automated tasks and analysing them with a number of statistics features.

To illustrate the potential and ease of use of the language, two examples using the water tank system have been described: Two PI controllers with different parameters and Autotune of a PI controller.

At the moment, the implementation of our experiment language only supports interaction with java VRLs created with EjsS. We are working to provide a new implementation compatible with javascript laboratories generated with EjsS.

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Inquiry-Based Remote Controlled Labs

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At Vrije Universiteit, Amsterdam, undergraduate physics students conduct experiments like researchers: inquiry based labs allow students to define their own research questions, set up and conduct experiments, and communicate through written reports, posters and presentations. A number of remote labs (RLs) have been developed that meet the same objectives. To accommodate senior high school students in the Netherlands, these RLs have been adopted to facilitate their research projects. This work presents examples of four of these RLs.

1 Introduction

The first remote labs (RLs) in the Netherlands were developed under the *e-Xperimenteren+* project about ten years ago by the Digital University, a consortium of ten universities (Bedaux et al., 2005, both papers). A pool of 12 remote experiments were developed, aimed at higher education. Vrije Universiteit in Amsterdam participated in this project with a number of RLs programmed in LabVIEW (National Instruments). Over the last few years, several new RLS have been developed, much more user-friendly accessibility to RLs has been arranged, and the need to download the software together with a LabVIEW runtime engine has been removed. At present, the RLs are still programmed in LabVIEW but run directly in a web browser[1].

The RLs resemble real hands-on experiments in the lab as closely as possible, offering undergraduate students the freedom to define their own investigation. However, one limitation imposed by RLs is that students should be able to conduct the experiments without any direct involvement by a supervisor. The opportunity to discuss research questions, work plans, data analysis and so forth, which is considered essential in conducting research, is limited to online chat sessions at best, or is completely absent. Supporting instructional materials and/or references must be provided to accommodate students. It is a challenge to draft these in such a way that a research environment can be emulated as closely as possible.

Senior high school students in the Netherlands have to conduct a research project and often turn to universities for support. The supporting materials offered with the RLs for undergraduate students and for senior high school students differ. The high school materials guide students through the experiments at their level. Although the guides are usually somewhat above the high school level, the students can still conduct slightly simplified open inquiry based RLs relative to undergraduate students. The actual experiment is conducted using the same experimental setup, but in general the data analysis features are somewhat reduced.

1 There still is a need to install MS Silverlight as a plug-in. The latest version of some browsers (e. g. Chrome and Edge) do not support MS Silverlight. Switching to HTML5 will be done as soon as National Instruments supports it.

Mulder, J., Blankert, P., & Kuik, G. (2016). Inquiry-Based Remote Controlled Labs. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 103–110). European Physical Society.

For each of the RLs, several webcams are available to monitor relevant parts of the setup throughout the experiment. Particularly for classroom settings/demonstrations, viewer programmes are available. In a viewer programme, the RL interface is shown in a web browser and the viewer can exactly monitor anything that the person who controls the experiment does. Furthermore, the viewer can download real time results of the RL and analyse the experimental data. Data analysis software built into the RL interface can also be downloaded and used offline.

RLs on Laser Remote Sensing to study photosynthesis, Laser Doppler Anemometry, Positron Emission Tomography and the Synthesis of Methyl Orange in a Micro Reactor will be discussed as examples below.

2 Laser Remote Sensing to study photosynthesis

Laser remote sensing (LRS) is a general term to describe the procedure of gaining physical information on systems from a large distance with the aid of lasers. The technique is also referred to as LIDAR: light detection and ranging. The principle is simple: light from a laser strikes the system of interest and the returning light is detected by a telescope and analysed. The technology has continually developed since the 1970's, but rapid advances in laser technology and computers over the past ten years have been especially fruitful in opening up a wide variety of applications. Most often, LRS is used in atmospheric and environmental studies conducted from an airplane, minivan or satellite. These studies typically measure concentrations of pollutants, map cloud formation and monitor agricultural crops for stress. The latter example is addressed in the experiment chosen here. This is a special case of LRS, since instead of investigating scatter properties, one monitors the laser-induced fluorescence (LIF) of photosynthetic systems.

Photosynthesis is the process by which plants, algae, cyanobacteria and some other bacteria chemically store energy from solar light. This process involves many different protein complexes and reaction steps, all tuned for maximal energy conversion (implying minimal heat loss) and directionality. Photosynthesis is optimised for low-light conditions and several mechanisms exist to dispose of excess energy. Here, we investigate the fluorescence pathway.

Fluorescence spectroscopy provides an excellent way to investigate photosynthetic processes in green plants. Spectrally, the photosystems PS1 and PS2 can be distinguished since the PS1 antenna contains a number of chlorophylls that absorb at longer wavelength (i.e. lower energy) than most of its other chlorophylls and of the chlorophylls embedded in the PS2 complex. Excitation energy in the PS1 antenna tends to focus on these special chlorophylls, which give rise to fluorescence at considerably longer wavelengths than those of PS2.

The normal environment for a plant is a low-light environment because most of its leaves will be in the shade of the few highest ones. In a so called dark-adapted plant, the fluorescence quantum yield is very low. The main reason for this is that the usual decay channels of the singlet-excited state of chlorophyll (fluorescence, internal conversion into heat, intersystem crossing into a triplet state with total spin S=1) are circumvented by the energy and charge separation processes of photosynthesis.

When the amount of available light increases, however, the photosynthetic pathway becomes saturated and the plant reaches the maximal rate at which CO_2 and H_2O can be converted into O_2 and organic matter. Under these conditions, the fluorescence yield increases, because the excited state of the chlorophylls cannot decay photosynthetically anymore and the decay routes of other processes (fluorescence, internal conversion, intersystem crossing) increase.

For this reason, most plants take extra precautions under high-light conditions by changing the antenna structure somewhat—the result being strongly increased decay by internal conversion. This prevents accumulation of triplet states, and has as the secondary effect of decreasing the fluorescence yield rather strongly.

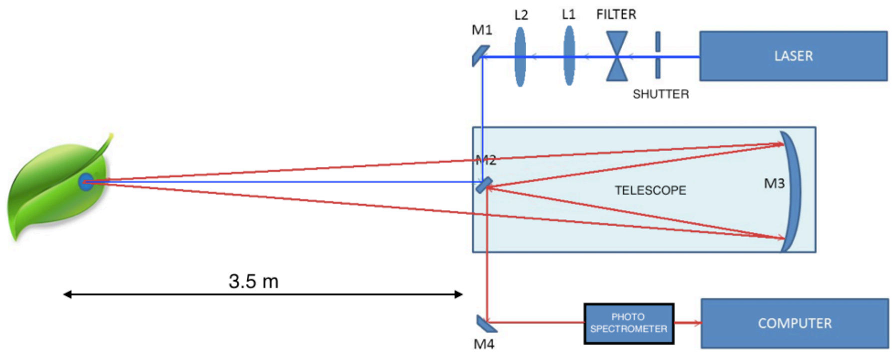


Fig. 1. Schematic of the LRS setup. M1-M4 are mirrors, L1 and L2 are lenses. The filter is a rotatable grey density filter used to adjust the light intensity of the laser beam exposing the leaf. The fluorescence light is collected by a telescope and fed into a photo spectrometer. The plant is positioned on a rotatable platform allowing the user to position the laser beam on a leaf.

The ability of a plant to show these types of fluorescence quenching processes depends on a built-in photosynthetic apparatus; single chlorophylls will not show this kind of behaviour.

Thus, the fluorescence yield of green plants shows a number of dynamic variations that largely depend on the specific light conditions and on the capability of the plant to react to changes therein.

Using LRS, one can increase the light intensity locally and in a controlled condition. In that way, one can obtain information on the quality of the vegetation under investigation.

A schematic of the experimental setup used in the RL is given in Fig. 1. The plant is positioned on a rotating platform that can be controlled through the RL to point the laser beam onto a leaf. Using a rotating neutral density filter, the intensity of the laser can be adjusted. A shutter controls whether or not the leaf gets exposed to the light. The fluorescence light is collected with a telescope and analysed using a photo spectrometer.

The RL allows the recording of the fluorescence spectrum, which will typically show double peaks for the PS1 and PS2 photosystems. The RL also allows for the measurement of fluorescence time decay for two selected wavelength regions over which the overall fluorescence is integrated (see figure 2).

For undergraduate students, an off-line spectrum analysis programme can be downloaded to carry out analysis of the fluorescence spectra. The fluorescence spectra can be fitted with Gaussians and the time decay signals can be fitted with exponentials. Based on this information, PS1, PS2 and the role of chlorophylls *a* and *b* can be studied.

For senior high school students, the theoretical background is presented at a somewhat lower level and the analysis of data is simplified (no analysis of time decay measurements is performed). Details on the RL and supporting materials can be found at: http://www.nat.vu.nl/~gerritk/Files/LRS_start.html.

3 Laser Doppler Anemometry

Laser Doppler Anemometry (LDA) is a technique used to measure velocities of flows or, more specifically, of small particles in flows. The technique is based on the measurement of laser light scattered by particles that pass through a series of interference fringes (a pattern of light and dark surfaces). The scattered laser light oscillates with a specific frequency f_d that is related to the velocity of the particles v_x. If the flow is perpendicular to the fringes the relation between f_d and v_x depends on the angle 2θ between the two intersecting laser beams and the wavelength λ_0 of the laser light:

$$f_d \approx 2 \sin\theta \frac{v_x}{\lambda_0} \tag{1}$$

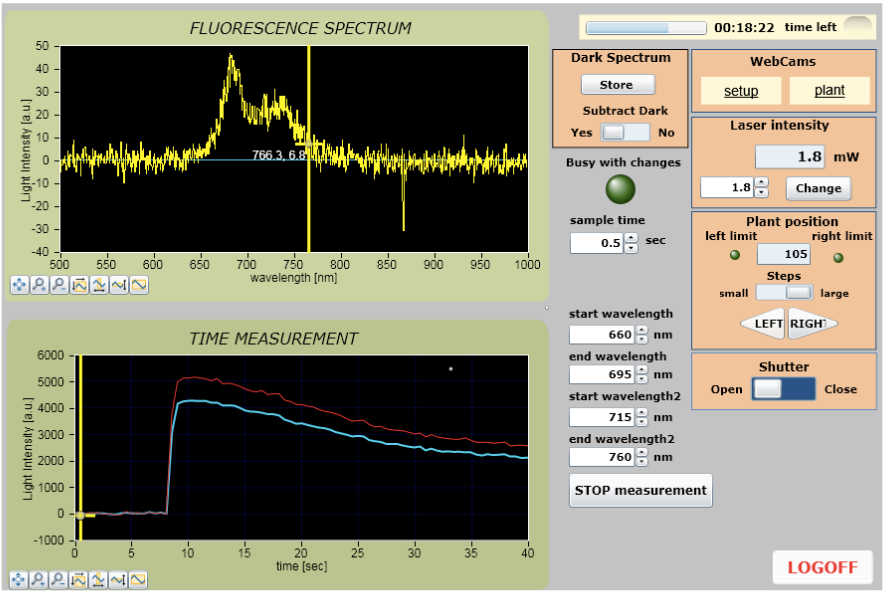


Fig. 2. Interface of the LRS experiment. The upper graph shows the fluorescence spectrum, the lower graph shows the time decay traces for integrated fluorescence signals in the wavelength regions of 660-695 nm and 715-760 nm respectively. When the measurement is stopped, the interface adds an option to save the experimental data. A separate data analysis programme is available to fit the upper graph with a double Gaussian and the lower traces with exponential decay curves.

This technique has numerous advantages over others. For instance, there is no need for physical contact with the flow, so no disturbances occur and the technique can be applied to flows of highly reactive or extremely hot fluids and the like. Furthermore, a relatively high spatial resolution can be obtained by focusing the two laser beams. These characteristics make LDA a valuable measuring technique with many applications. For example, LDA can be used for airflow measurements within combustion engines and airplane engines to improve fuel efficiency or to reduce pollution and airplane noise. Applications for LDA can also be found in the medical field, e.g. to perform blood flow measurements.

The senior high school experiment is introduced using a medical context: studying the flow rate of blood to detect arteriosclerosis. Students are introduced to LDA through a handout that introduces the relevant theory step-by-step. The materials include a set of exercises for students to determine whether they have mastered the content.

After covering the basics, students are exposed to the experiment interface and operation of the RL. From there, students are challenged to decide for themselves what they would like to investigate. The tools available to them are similar to that of undergraduate students. However, upon introducing LDA, simplifications are made to make the topic accessible to high school students. In the analysis of experimental data, students cannot go as much into depth as what is required of undergraduate students.

The experimental setup of the LDA is shown in Fig. 3.

In the RL, the flow tube has a varying diameter. The flow tube can be moved to position the overlapping laser beams to a desired diameter, and across the tube measure a velocity profile (which, in the case of a laminar flow, results in a parabolic velocity distribution as shown in the schematic of the setup provided in Fig. 3). In the RL the temperature (which determines the viscosity of the water running through the tube) and flow rate can also be adjusted (see Fig. 4).

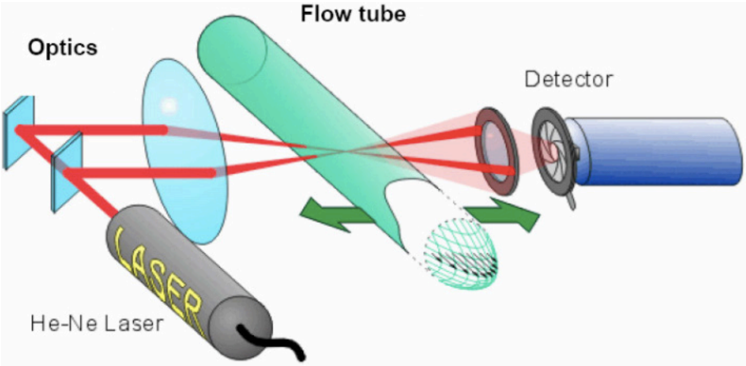


Fig. 3. Schematic of the LDA setup. The overlapping region of the laser beams forms the measurement volume. Light waves impinging on small particles are scattered through Mie scattering. The diaphragm blocks the laser beams. Scattered light passing through the diaphragm is focussed on a photo diode.

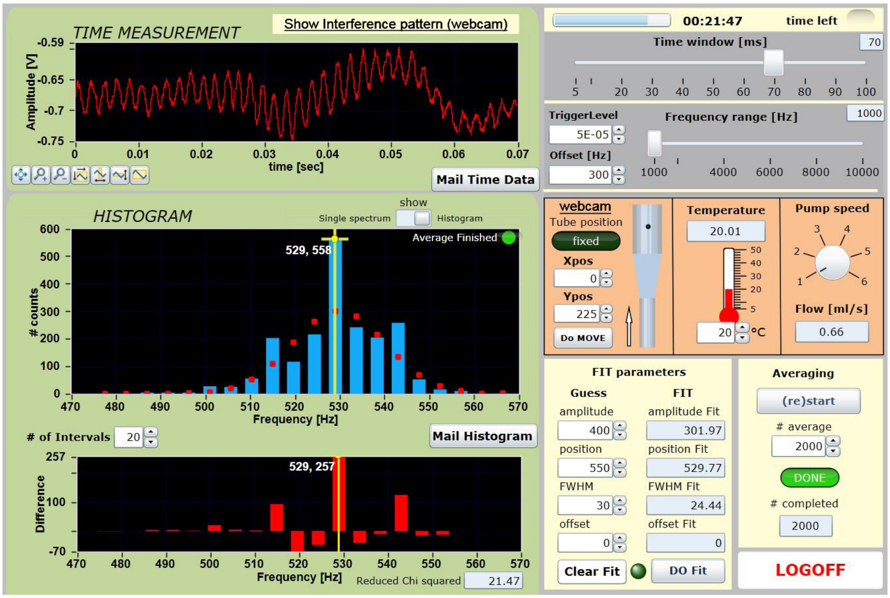
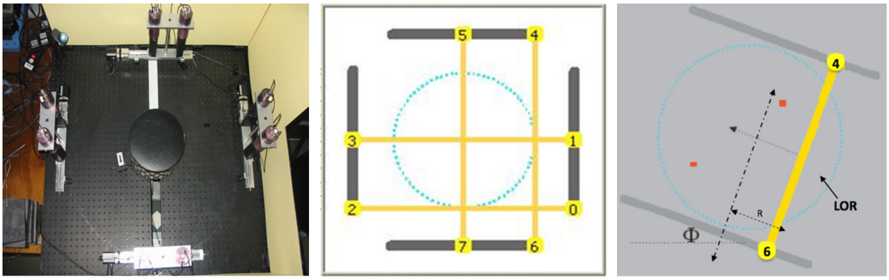


Fig. 4. LDA interface. The top panel shows the measured data, the centre panel shows a histogram distribution of the highest peaks in the FFT frequency spectra obtained from time measurements, with a Gaussian fit superimposed. The residual errors of the fit are shown in the lower panel.

The AC photodiode signal records frequency bursts as particles pass through the measurement volume. Using a fast Fourier transform, a real-time frequency spectrum is obtained, which can be fitted with a Gaussian to determine the frequency and frequency spread, which in turn can be translated into a centre velocity and velocity spread. Because of the strongly varying signals which are very sensitive to disturbances, students can opt to average over a large number of samples, which makes the experiments very suitable for exposing undergraduate students to detailed statistical error analysis.

Further details on the RL and supporting materials can be found at: http://www.nat.vu.nl/~gerritk/Files/LDA_start.html.



(a) (b) (c)

Fig. 5. Top view of PET setup (a) with the head containing the radioactive sources at the centre and 4 sets of detectors, whose arrangement is shown in (b) as well, and the line of response (LOR) as a detector set is scanned along the dark grey lines at an angle Φ (c). The radioactive sources are marked in red.

4 Positron Emission Tomography

Positron Emission Tomography (PET) was chosen as a RL for several reasons: it is too expensive and dangerous to conduct as a hands-on experiment, it is an illustration of a diagnostic modality used in hospitals, students are trained in image reconstruction/medical imaging techniques, and medical physics seems to attract students.

The PET scanner is a simplified version of the one used in hospitals: it is equipped with only 8 detectors, positioned as shown in Fig. 5a. These detectors can move along the x- and y-direction while the head in the centre can be rotated. The head contains radioactive sources (two strong and one weak) that are positioned differently in each experiment. A real PET scanner contains a ring with detectors covering the full circle. Measurements using the simplified scanner take a bit longer, but do so at an affordable cost. Fig. 5b/c show how sets of detectors may detect coincident gamma photons emitted through the annihilation of a positron-electron pair along the lines of response (LORs). When coincidences are measured by opposing detectors, the radioactive source must be located along the LOR. By rotating the head, data can be collected over an angle of 360 degrees. Crossing LORs pin-points the location of the radioactive sources allowing for image reconstruction using a back-projection algorithm.

While conducting a measurement (which takes some time) students can familiarize themselves with the back projecting imaging technique using a simulation programme. In the simulation programme, one or several radioactive sources of different sizes and strength can be selected. A single set of detectors can scan along a line and then be rotated over an angle Φ (Fig. 5c). In this way, the reconstruction of a 2D and 3D (includes the intensity) image is obtained. The simulation guides students through the limitation of the direct image reconstruction and introduces filtering techniques in the back projection to improve image reconstruction. To make this more challenging, a real MRI image of the brain can be superimposed on the projected data. When students are familiar with image reconstruction techniques, they can try to analyse real recorded data. The PET RL will be available from August 2016 upon the release of software revisions due to replacement of the detector electronics at: http://www.nat.vu.nl/~gerritk/Files/PET_start.html.

5 Synthesis of Methyl Orange in a Micro Reactor

The synthesis of methyl orange (see Fig. 6) is an exothermic reaction and requires cooling with ice as the diazonium coupling is a potentially explosive reaction. At universities and in industry, such reactions are studied in a micro reactor for this reason. Furthermore, diazonium salt and methyl orange are toxic.

In the RL, student can investigate and optimize conditions for the synthesis of methyl orange in a micro reactor. The synthesis of methyl orange in a micro reactor involves the

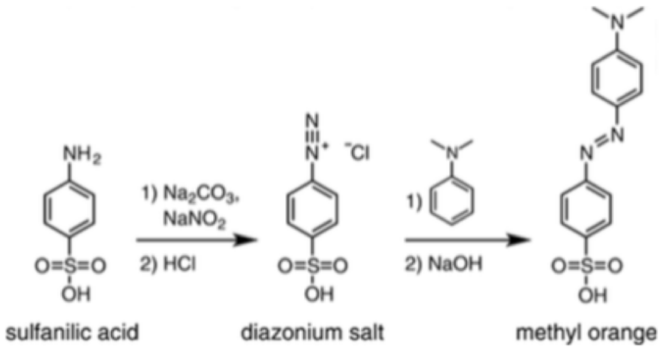


Fig. 6. The synthesis of methyl orange (from: Van Rens et al., 2013).

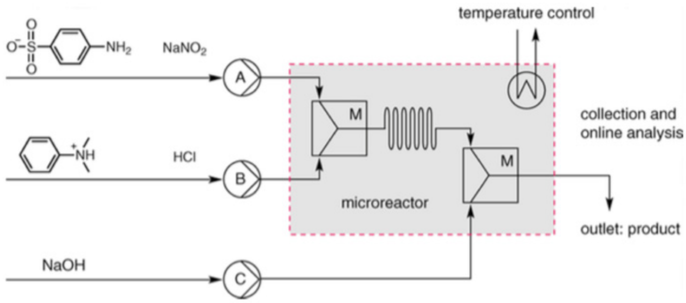


Fig. 7. Schematic of micro reactor (from: Van Rens et al., 2013).

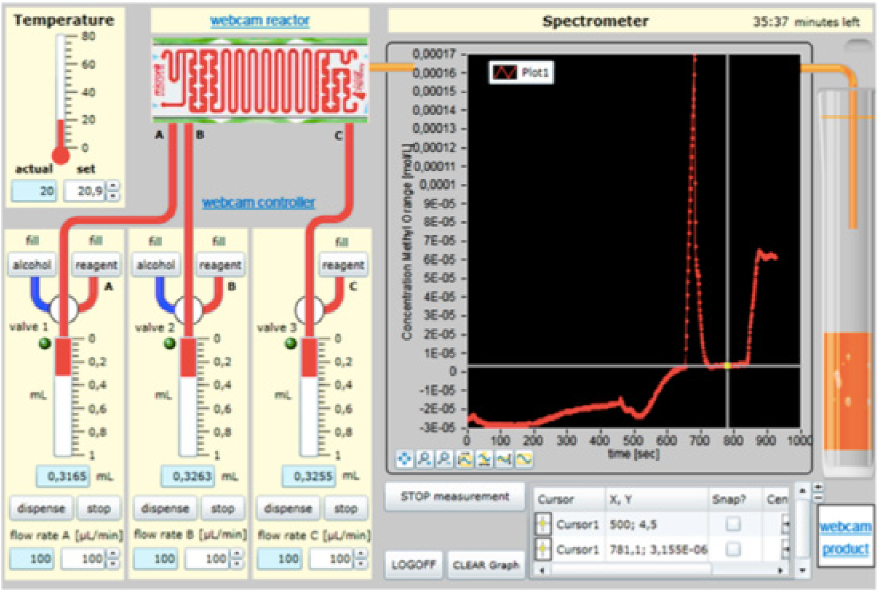


Fig. 8. Interface of the micro reactor (from: Van Rens et al., 2013).

mixing of three solutions of chemicals. The reactor is schematically shown in Fig. 7, while the programme interface is shown in Fig. 8.

Flow rates and ambient temperature of the chemicals mixed can be varied in order to maximize the yield of methyl orange. The formation of methyl orange can be monitored in real time by its colour change, which is determined using a photo spectrometer.

Originally, the RL for the synthesis of methyl orange in a micro reactor was set up as a competition among (international) students in 2013. Before students actually conduct the experiment, they work through a set of handouts related to flow chemistry and are challenged to come up with a research protocol to conduct the investigation. Part of the preparation involves hands-on lab experiments which can be safely carried out in school (Van Rens et al., 2013). For this reason, the RL is part of a chemistry module, which in most cases is covered in a classroom setting. Since then, over a thousand students have conducted the experiment. Further details on the RL and supporting materials can be found at http://www.chem.vu.nl/en/voor-het-vwo/online-scheikunde-experiment.

6 Concluding remarks

The RLs available at Vrije Universiteit Amsterdam (there are still others) allow students a great deal of freedom in conducting inquiry-based experiments at an appropriate level of complexity, making them suitable for senior high school students and undergraduate physics students.

RLs are offered to our undergraduate students, students at the Open University, at Windesheim College (a teacher training college) and as part of an in-service lab course for physics teachers. Senior high school students use the RLs described above for research projects. In the coming years we expect to expand to a larger number of RLs.

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Blended Learning With Virtual Laboratories in the Context of Application Oriented Education in Physics

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By connecting real experiments with multimedia tools we create virtual laboratories that improve the practical physics courses of undergraduates – irrespective of place, time and device used. In accordance with the philosophy of blended learning, virtual labs are embedded in traditional formats like lectures, exercises or tutorials. Thus, the main goal is to establish virtual laboratories as an inherent and sustainable part of the teaching program.
We provide insight into a virtual laboratory from the project Open MINT Labs (*OML*), and discuss how to motivate or activate students for both the practical and theoretical content. In this context, some multidisciplinary ideas are presented. On top of that, the virtual laboratories are accompanied by a long-term empirical evaluation whose preliminary results are analyzed from the student's point of view.

1 Introduction

Practical courses play an important role in the quality of post-secondary education in natural and engineering sciences, particularly with regard to advanced and specialized skills (Zwickl, 2013).

For this reason, the joint project *Open MINT Labs* (*OML*) – funded by the German Ministry of Education and Research (BMBF) – emphasizes the development and scientific investigation of virtual laboratories (Open MINT Labs, 2015). The project *OML* is shared among Rhineland-Palatinate's Universities of Applied Sciences Kaiserslautern, Koblenz and Trier.

This article is structured as follows: First of all, the overall concept of the virtual laboratories from the project (short: *OML*-lab) will be introduced. Afterwards, in chapter 3, we pick up the virtual *OML*-lab *Viscosity* as an example of a concrete implementation of multimedia in physics teaching and learning. In chapter 4 we go beyond the scope of the present lab and show possible connections to other fields of physics. Chapter 5 refers to the assessment from the student's perspective before we conclude with a summary and outlook.

2 Concept and Implementation

Every virtual *OML*-lab is based on a modular concept, as elaborated on by the project team, taking into account recommendations from education theory and media design as well. The structure consists of the following five self-explanatory building blocks: *Orientation*, *Basic Information*, *Experiment*, *Application,* and *Reflection*. These supports coach the learner from the point of establishing basics to the transfer of knowledge when answering questions from everyday life or solving challenging problems from research and industry with a project character. The potential for interactive learning with multimedia is exploited (e.g. methods of direct feedback and tools of self-evaluation) while the virtual lesson encourages learners to work independently.

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The main idea behind this virtual lab concept is to offer a complete learning environment catered to the individual learner. At the same time, the concept will provide a basis for other formats and learning scenarios – one can imagine the cooperative learning in exercises or lectures in a *flipped-classroom* format (Leibniz-Institut für Wissensmedien (IWM), 2015). Thus, some blocks are well-suited for such a content-sharing, too.

A unique selling point of *OML* is the inclusion of regional partners from industry to illustrate the relevance of the learning content for the student's later working life (see 3.4). Authentic interactions stimulate the learner's activity: The task may be to analyze the video of a physical or technical process, to perform a parameter study by applying numeric simulations or to examine a realistic three dimensional animation with *CAD* (computer aided design).

The virtual labs are implemented in the widespread learning management system *OpenOLAT* (Virtueller Campus Rheinland-Pfalz (VCRP), 2015). Since all virtual elements are programmed on the basis of modern languages, like html-5 and css-3, platform independence is guaranteed.

3 The Virtual Lab Viscosity: Example of a Concrete Realization

This chapter focuses on the concrete implementation of a typical virtual laboratory from the project *OML* in order to demonstrate how to meet the general conditions above as well as pedagogical aspects. For this purpose, we discuss the virtual laboratory Viscosity (*OML*-lab *Viscosity*, 2015) in more detail. This *OML*-lab is part of the practical physics courses at the University of Applied Sciences, Trier. Students of physics engineering, electrical engineering, machine engineering, process engineering, medical technology and medical informatics can benefit from this virtual offer.

3.1 Orientation

When entering the virtual *OML*-lab the learner obtains an overview of the content that is structured in five building blocks and introduced with eye-catching pictures and some lines of text to provoke the learner's curiosity. Since individuals differ in background, it is left to them to decide how to navigate: Either in a chronological order from the first block to the next one or by skipping between them.

The first block, called *Orientation*, aims to motivate the learner and to help with the organization, time management and mental preparation of the learning process.

While the initial pages of a textbook are reserved for the table of contents, the *OML*-lab places a word cloud that collects the relevant *Keywords* at the beginning. Some may be already familiar to the learner and can be linked to previous knowledge, while others may be unknown but provide a rough idea of what the virtual laboratory is concerned with.

The subsequent section classifies the importance of the topic for physics in general, but also with respect to the student's perspective and the role it plays in their branch of study. In the special case of the *OML*-lab *Viscosity*, a video taken from youtube (Oilfino, 2012) is chosen to attract the learner's attention. In the video, small spheres of steel are sinking in glass tubes that are filled with different sorts of motor oil. This comparative demonstration leads to the key question: *"Which oil has the lowest viscosity, and what does this quantity describe?"* Later on, in the fourth block *Application* (see 3.4), we will again return to this opening video – but then it is the learner's turn to perform the experiment themselves.

Next, the *Prerequisites of Learning* here, the definitions of density and pressure, as well as background knowledge of buoyant forces, the principle of Archimedes, Newtonian mechanics, and the laws of motion are specified. Also provided are recommended literature and some tips or special advices from the responsible instructor. The *Objectives* are then made transparent. Here, *"The learner is able to: (i.) describe the falling ball viscosimeter in [their] own words, (ii.) handle the apparatus in order to determine the viscosity of several fluids from the virtual experiment, and (iii.) transfer the learning content to similar problems"* (*OML*-lab *Viscosity*, 2015). Finally, the required time (here: 30-60 minutes) is estimated,

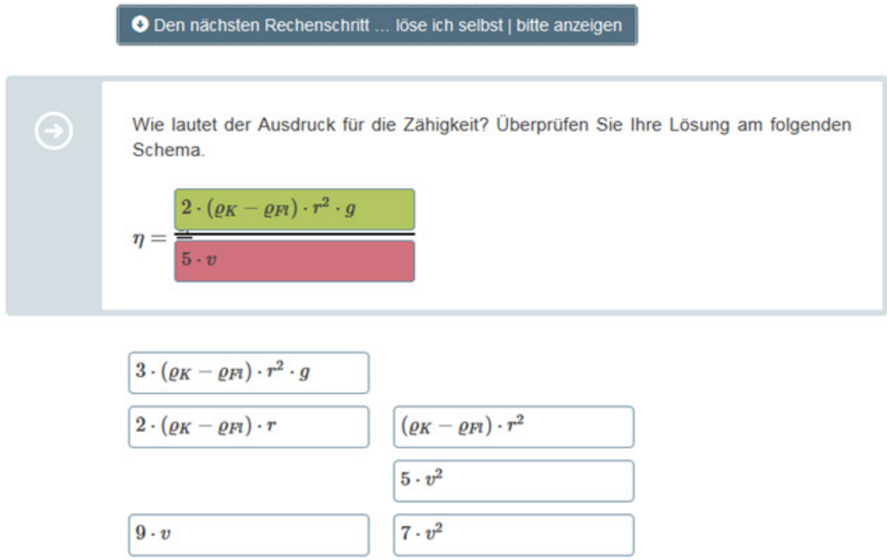

Fig. 1. Example of an exercise to gain the learner's involvement during the derivation of the viscosity from equ. (1). Whereas the numerator is correct (indicated in green color) the denominator is not right (signaled in red).

and a *Directory* provides information about the content and the activities the learner is faced with in the following building blocks.

3.2 Basic Information

Before the student starts with the experiment in the virtual or real laboratory, the *Basic Information* block provides a tailored theory section for background knowledge.

In the present *OML*-lab this block is subdivided into three topics: *"Friction in Fluids and Viscosity", "Laminar Fluid Dynamics through Pipes"* and *"Falling Ball Viscosimeter"*. For the sake of clarity, each of the three topics can be faded in separately just by clicking on the corresponding title line.

In general, conveying abstract theory via e-learning is difficult. To prevent learners from feeling like they are reading a conventional textbook, the capacity of modern media for interactivity should be exploited. Let us make some suggestions from the *OML*-lab: Longer sections of information should be interrupted by questions directed to the learner. If the derivation of a formula is being carried out the learner will be invited to continue with the next step by selecting the option *"I will try myself"* or *"Please show solution".* A rather playful approach illustrates the snapshot in fig. 1. Here, the expression of the viscosity (equ. 1), which is necessary to analyze the measurements with the falling ball viscosimeter, is completed by dragging the fragments of the formula into the two blank boxes – representing the numerator and the denominator respectively. Whether the learner's answer was correct is indicated by color code (green indicates the answer was right, while red indicates it was wrong).

$$\eta = \frac{2 \cdot (\varrho_K - \varrho_{Fl}) \cdot r^2 \cdot g}{9 \cdot v} \quad (1)$$

In equ. (1) ϱ_K denotes the density of a sphere with radius r and the constant sinking speed v, where ϱ_{Fl} is the density of the liquid and g is the acceleration of gravity.

Following the *Basic Information* block several *Hypotheses* can be identified, and a so

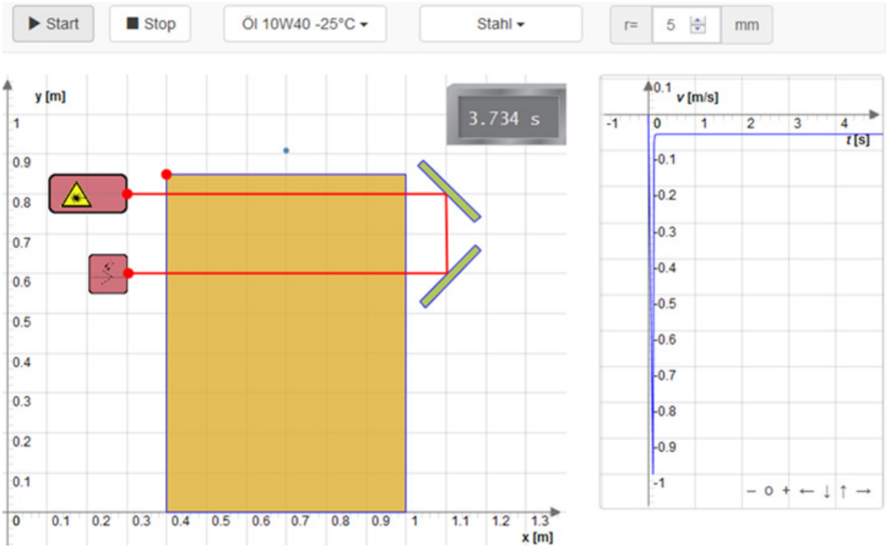

Fig. 2. Snapshot of the virtual falling ball viscosimeter in the *OML*-lab 'Viscosity'. In the menu the simulation can be executed after the fluid, the material and radius of the sphere are chosen. On the left side the interactive set-up is sketched with the starting position of the sphere (small blue dot) and the arranged light barrier. The diagram on the right side plots the time evolution of the sinking speed. Note its initial steep drop which is caused by the falling motion through the air.

called *Basic Check* – which can be either mandatory or obligatory – gives the learner the opportunity to review the acquired knowledge once more before proceeding with the virtual experiment.

3.3 Experiment

The centerpiece of every virtual *OML*-lab is the *Experiment* block as it prepares the scientific work in the real laboratory. However, it could also be the case that there exists no real counterpart of the virtual laboratory, e.g. when the experiment would be too expensive or too dangerous. Very similar to a conventional lab record, the block comprises the sections *Preparation of the Experiment, Assignment of Tasks, Conduction of the Experiment with Data Acquisition*, and *Analysis and Interpretation*.

In the section *Preparation of the Experiment* some hints prompt the learner to think about the design of the experiment and its operation in terms of the *Assignment*: "*(i.) The material of the sphere has to be chosen properly. What would happen if you perform the experiment with a wooden sphere? (ii.) The product of the radius of the sphere and its sinking speed has to be small enough. Why do you think this condition must be fulfilled? (iii.) The upper light barrier must not be too close to the height where the falling ball starts. How do you think the measured quantities and the viscosity would be affected if this were not considered? Why?*" (*OML*-lab *Viscosity*, 2015).

After having chosen a proper sphere (a small ball of steel is ideal), and having placed the light barrier at a position the falling sphere has a constant sinking speed (otherwise the assumption made by Stokes friction is violated), the experiment can be started in the section *Conduction of the Experiment*. However, the *freedom* of the experimentalist to make errors due to incorrect operation of the apparatus is intentionally maintained. One objective is that the learner becomes aware of typical sources of error.

Figure 2 depicts a snapshot of the virtual falling ball viscosimeter. The user interface is constructed by means of *GeoGebra* (GeoGebra, 2015) whereas for the generation of the

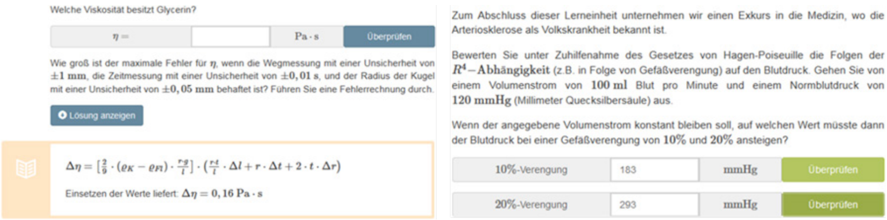

Fig. 3. Left: Determining the viscosity of glycerin; the solution of the error propagation is faded in. Right: Relating the law of Hagen-Poiseuille with an application from medicine; shown is the feedback control.

menu bar and the plot window an open-source tool kit from the University of Bayreuth is used (JSXGraph, 2015). The media design tries to keep the operation of the viscosimeter intuitively clear. In the menu bar the fluid whose viscosity is to be measured can be selected from a list (here: water (20°C), glycerin (20°C), motor oil 10W-40 (-25°C), honey (20°C)); similarly the material (here: beech, rubber, glass, steel, lead) and the radius of the sphere (here: 1 to 99 mm) can be chosen. Then, the upper and lower part of the light barrier (represented by a symbol of a laser and a diode) has to be arranged by moving the red dots at both ends of the laser beam (see fig. 2, left). The mathematical calculation of the motion of the falling ball is based on Newton's law of force by applying an approximation procedure of the *Runge-Kutta* method to solve the differential equation.

Finally, in the section *Analysis* and *Interpretation* the learner determines the viscosity from equation (1), and can check the obtained values via a feedback function.

3.4 Application

The ultimate goal of the *Application* block is to deepen the knowledge – either by doing *Rerun Exercises*, or by training the *Transfer to Novel Problems*. In this context, authentic examples of application from industry are preferred (Roth et al., 2014). Thanks to such a problem-oriented approach, the relevance of the learning content can be clarified.

For instance, a first rerun exercise asks the learner to determine the viscosity of glycerin for some given experimental parameters. This is continued by an analysis of the corresponding error propagation; here, assistance for the solution is available (fig. 3, left).

To complete the educational form fit we return to the motivation video with the falling sphere in the motor oil as introduced in the *Orientation* (see 3.1). The task assigned to the learner is to check if the oil denoted with "10W-40" fulfills the criterion as given by SAE standards, which demand a viscosity of at most 7000 mPa · s at a temperature of -25°C. The corresponding virtual experiment is conducted in fig. 2. As the steel sphere ($r = 5$ mm, $\varrho_{\mathrm{Steel}} = 7850\ \mathrm{kg/m^3}$) needs 3.734 s to pass the light barrier separated by 0.2 m it follows a sinking speed of $v \approx 5.4$ cm/s. With the known density of the oil ($\varrho_{\mathrm{10W\text{-}40}}(-25°\mathrm{C}) = 7850\ \mathrm{kg/m^3}$) one obtains a viscosity of 7.1 Pa·s – slightly exceeding the limit value. Another example refers to an application in medicine as described in the next section (see 3.5). This choice of applications acknowledges the fact that many learners study machine engineering or medicine technique.

3.5 Reflection

In order to ensure the achieved learning results – but also to stimulate a faithful recall of the learning content and learning process – the closing *Reflection* block combines a *Summary* and *Self-Evaluation*.

The most important formulas or rules of thumb are compiled in a single box that is printable. In addition, a check list with questions about the theory or the experiment prompts the learner once more, e.g. *"Have I understood the measuring principle?"* or *"Do I know the relevant quantities for the investigation? Please list them."*

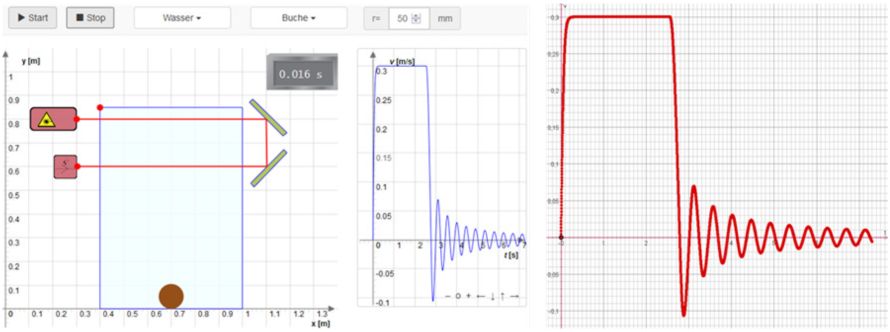

Fig. 4. Left: A wooden sphere (r=50 mm, ϱ_K =690 kg/m^3) rises up from the bottom of the viscosimeter. Middle: Oscillations recorded with the *OML*-lab 'Viscosity'. Right: Control simulation using the program 'Fluxion' from (Lück, 2015). For the modeling of friction, instead of Stokes law, the exact formula of Oseen is used in both cases. Furthermore, it is taken into account that the buoyant force changes when the sphere is only partly under water. Surface and interfacial tension is neglected.

Finally, an *Excursion* is undertaken to the field of medicine. In this intervention of learning the increase of blood pressure due to vascular disease is of interest. By means of the law of *Hagen-Poiseuille*, describing the flow through pipes, the learner proves that in order to maintain a volume flow of 100 ml per minute a reduction of the initial vessel radius by only 10% leads to a dramatic increase of the blood pressure from 120 mmHg to 183 mmHg (see fig. 3, right). The result is impressive and alarming at the same time, and will encourage the learner to maintain a healthy lifestyle. In a similar manner, the functional principle of a *pneumo-tachometer* (an apparatus used in clinical practice to measure the volume flow of respiration) could be added. The virtual laboratory terminates with a *List of Links* and an *Outlook* to related *OML*-labs (here: the virtual *OML*-lab *Wind Tunnel*).

4 Going Beyond the Scope of the Present Lab

In the following, we discuss some further learning scenarios which can – after some modifications – be realized with the virtual falling ball viscosimeter.

First, it is feasible to study the laws of motion. The law of falling bodies can be proven when performing the experiment in air. This experimental variation is conducted in fig. 2 where the sphere is positioned at a height of h_0 = 5 cm above the surface of the liquid. The resulting impact velocity of $-\sqrt{2g \cdot h_0} \approx -1$ m/s is in good agreement with the value taken from the time-velocity diagram on the right side of fig. 2. However, when using the viscosimeter in the conventional operation mode, motion due to friction, as well as time dependent acceleration occurs (according to *Stokes law* the friction increases linearly with the sinking speed, see again the plot in fig. 2).

Secondly, when substituting the sphere of steel by a swimming body, the latter begins to oscillate around the surface of the liquid:

$$m \cdot \ddot{x} + b \cdot \dot{x} + D \cdot x = 0 \quad (2)$$

In this differential equation m denotes the oscillating mass, b is the damping factor and D quantifies the restoring force constant. As a first step, one could consider the undamped oscillation of a wooden cube with base area A in water. In this specific case the restoring force constant translates to $D = \varrho_{\text{water}} \cdot A \cdot g$ causing an oscillation frequency of $\omega = \sqrt{D/m}$.

For more advanced learners it may be challenging to see why the oscillation recorded for a wooden sphere is not harmonic anymore (see time-velocity diagram in fig. 4). Now, it has to be considered that the restoring force is not changed linearly with the depth at which the sphere is immersed in the water. This nonlinear motion may be analyzed by numeric calculation as implemented in the virtual viscosimeter. Another helpful tool is the

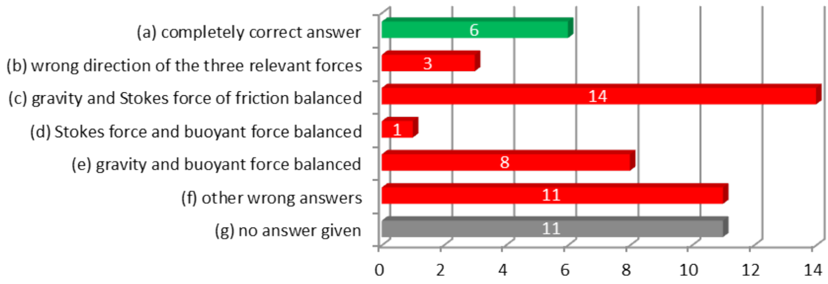

Fig. 5. Statistics to the question which forces are balanced in the falling ball viscosimeter for the situation of a constant sinking speed. For each category the number of answers (total: 54) is specified.

differential equation solver '*Fluxion*,' written by Stephan Lück from the University of Würzburg (Lück, 2011). In fig. 4 the oscillation is analyzed with both 'Fluxion' and the self-made program in the *OML*-lab.

Thirdly, as the simulation is programmed in a very flexible way (for more details see 3.3) it can be easily adapted to study the temperature dependent viscosity as described by the Arrhenius-Andrade relation, $\eta(T) = A \cdot e^{-T/b}$, whose empirical constants A and b may be retrieved from the virtual measurements at temperature T. Moreover, a thematic expansion to the class of *non-Newtonian* fluids is possible. Actually, the temperature dependence of the viscosity is the subject of an experiment in a real laboratory where a *Höppler Viscosimeter* is utilized.

These ideas show that the virtual experiment is suitable to teach and learn numerical simulation that is in line with a position paper of the German Council of Science and Humanities (Wissenschaftsrat, 2014). In addition, there is plenty potential to relate content from neighboring or different fields of physics, and to build bridges to other disciplines—making this approach multidisciplinary. The learner may benefit from a growing network of virtual laboratories since they provide an overview from a new perspective. In this context, the *OML*-lab *Viscosity* is related to the *OML*-lab *Wind Tunnel*, which already forms a lab network in the field of fluid dynamics. Furthermore, links to the *OML*-lab *Air Cushion Track (Part: Linear Motion)* and the *OML*-lab *Air Cushion Track (Part: Acceleration)* are activated.

5 Assessment

To continuously optimize the quality of the virtual laboratories developed by the project *OML*, the student's opinion is evaluated and they are encouraged to make suggestions for improvement. For a more extensive assessment of *OML*-labs we refer to Roth et al. (2015).

Although not representative, a first evaluation of the virtual laboratory *Viscosity* indicates that most of the six participants felt positively about the virtual lab, and give a school grade of 2.50±0.76. Altogether, from the *OML*-lab they felt quite well prepared for the real experiment (represented by 2.17±1.07 on a 7-ary Likert scale for this item), and would recommend the virtual lab to their fellow students (2.00±1.15 on a 7-ary Likert scale).

Moreover, the virtual viscosimeter was included in a lecture on physics in summer term 2015. During a classroom intervention, students were asked to calculate the viscosity of glycerin from the time taken for the sphere to pass the light barrier. A very similar exercise appeared afterwards in the written examination which was satisfactorily solved by most of the 54 students: Twenty-four calculated the correct viscosity (2 points), eighteen made some minor mistakes, four achieved 1 point, six achieved 0.5 points and two students either did not solve the question or gave a completely wrong answer.

Conversely, the comprehension question: *"Which forces are balanced in the operation mode of the falling ball viscosimeter?"* reveals a different result (see fig. 5). The majority of students had obviously huge problems understanding that during the constant sinking motion the force of gravity, less the buoyant force, is equal to Stokes force of friction:

$$F_{\text{gravity}} - F_{b\text{uoyant}} = F_{\text{Stokes}} \Leftrightarrow F_{\text{gravity}} = F_{\text{Stokes}} + F_{\text{buoyant}} \quad (3)$$

Surprisingly, only six (11.1%) out of 54 students answered this question correctly (a), whereas three (5.6%) name all participating forces but mix up the signs (b). Fourteen (25.9%) forget to mention the buoyant force (c), while one person (1.8%) ignored gravity (d). Eight (14.8%) were not aware of Stokes force of friction – although it is the essential quantity in the falling ball viscosimeter (e). Eleven (20.4%) have obvious shortcomings in their understanding of balanced forces (f), and the same number of students give no answer (g). The statistics from the written examination indicates that more effort has to be put into the explanation of the falling motion in the virtual laboratory (e.g. one could display the momentary vectors of the three relevant forces in the simulation).

6 Summary and Outlook

To summarize, we give a detailed description of a blended-learning-lab in the field of fluid dynamics and viscosity that is targeted to the preparation of students for their practical courses in physics. The virtual laboratory is structured of five building blocks named *Orientation, Basic Information, Experiment, Application* and *Reflection* offering a complete learning environment – but being flexible enough for other formats of learning, too.

The importance of application-oriented examples is emphasized as they create authentic learning scenarios for students who are not primarily interested in physics itself, but rather in what can be done with physics. In this context, the viscosity of motor oil is measured by the operation of a virtual viscosimeter. Moreover, concrete proposals are made to relate the experiments with the virtual falling ball viscosimeter to various fields of physics with minimal effort. For instance, the lab can be used straightforwardly to quantify oscillations with a linear or even a nonlinear characteristic.

As an innovative next step, we intend to implement an avatar who plays the role of a learning coach and is able to communicate with the learner “face to face”. An avatar might give feedback, offer tips, or trigger the learner’s reflection. Consequently, critical scrutiny of one’s own learning strategy may occur when deficits are immediately revealed.

Acknowledgement

The authors want to thank Christoph Hornberger for his suggestion to motivate the physics of fluid dynamics with applications to medicine. Helena Berg from the *Zentrum für Qualitätssicherung und -entwicklung (ZQ)* in Mainz is thanked for performing the project evaluation. Financial support from the German Ministry of Education and Research (BMBF) within the *Qualitätspakt Lehre* (support code: 01PL12056C) is gratefully acknowledged.

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SUPPORTING LAB WORK WITH MULTIMEDIA

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 (Aufschneiter, 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 unfimiliar equipment, they tend to focus on these experimental tools (Haller, 1999; Hucke, 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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 123–128). European Physical Society.

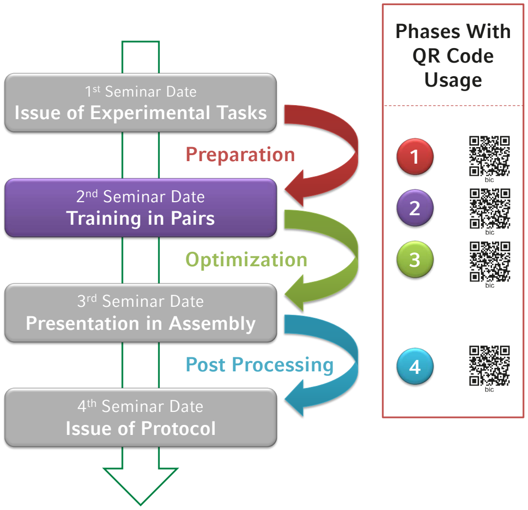

Fig. 1. Learning sequence in the seminar and stages with the possible use of QR codes. Students process an experimental task over three weeks. First, the task is issued, then there is one week of preparation time followed by training on experimental methods and presentations in person. Next, there is 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.

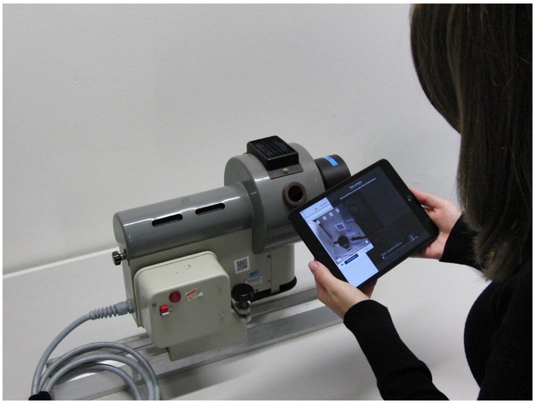

Fig. 2. Students can scan QR Codes from a task sheet or directly from a device.

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.

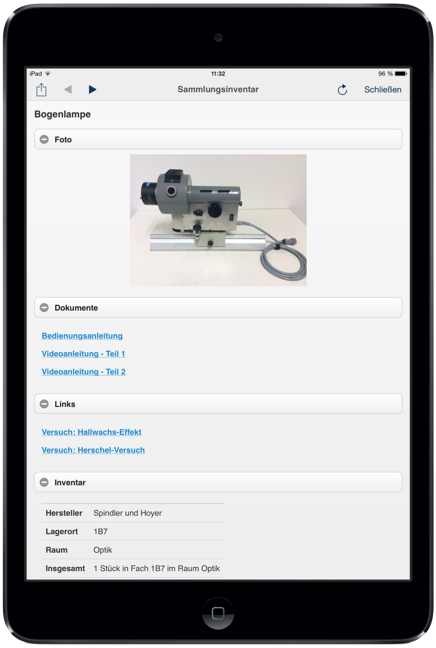

Fig. 4. After scanning the QR code a device specific web page will be displayed on the tablet, smartphone or PC.

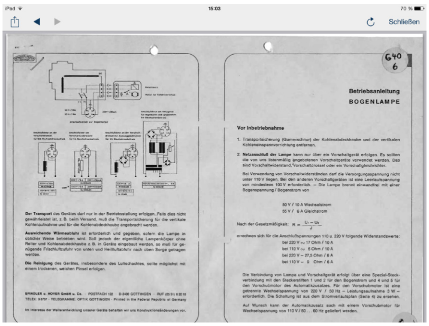

Fig. 5. Linked data sheet.

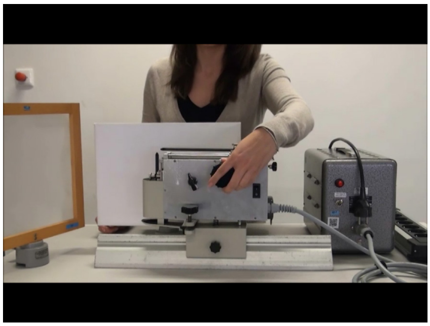

Fig. 6. Linked video tutorial.

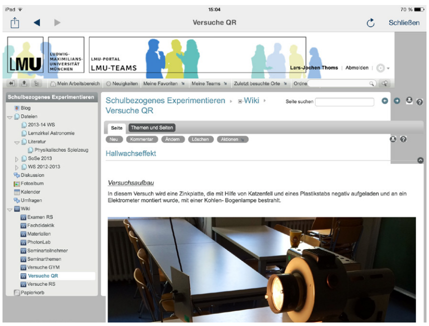

Fig. 7. Linked experiment instructions.

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

Group	1 Preparation	2 Training	3 Optimization	4 Post Processing	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	1 Preparation	2 Training	3 Optimization	4 Post Processing	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	1 Preparation (two weeks)	2 Training	3 Optimization	4 Post Processing	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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 129–134). European Physical Society.

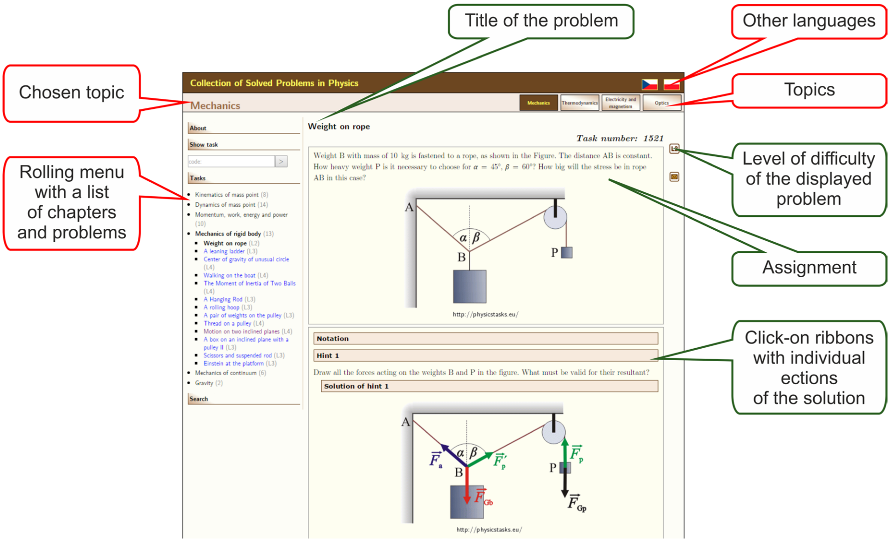

Fig. 1. Appearance of the Collection.

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.

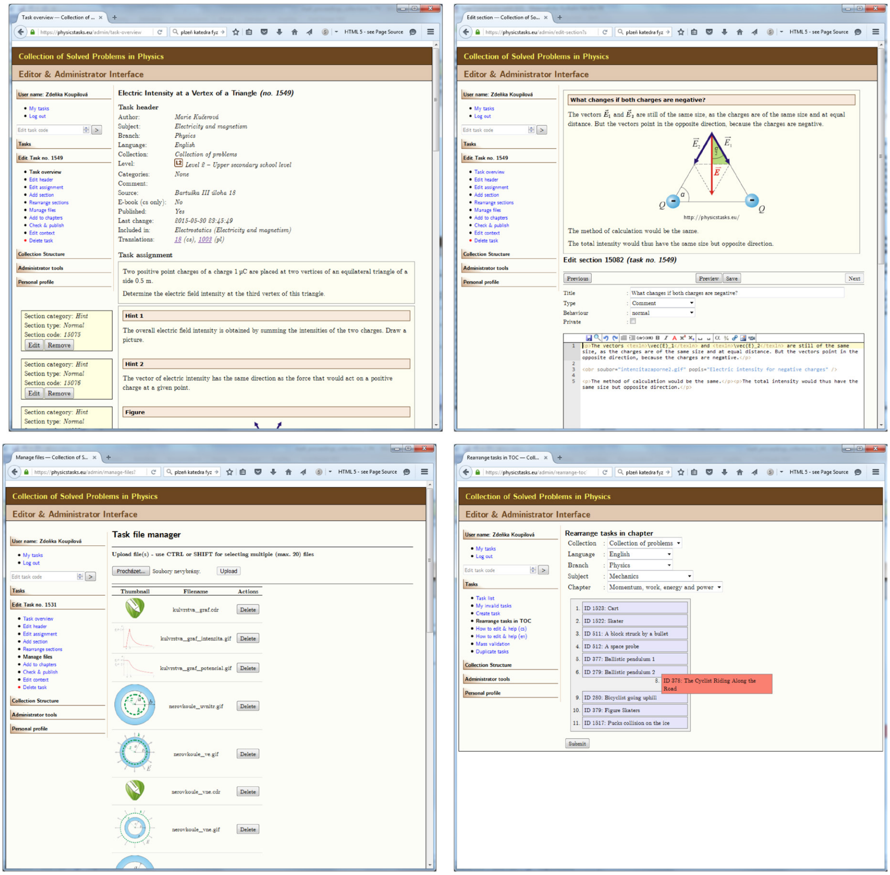

Fig. 2. Administration interface. Problem preview window (upper left), text editing window (upper right), file management window (lower left) and Collection structure changes (lower right).

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 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).

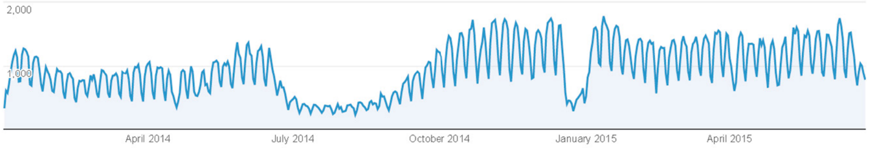

Fig. 3. Number of unique visitors per day (all Collections and languages together).

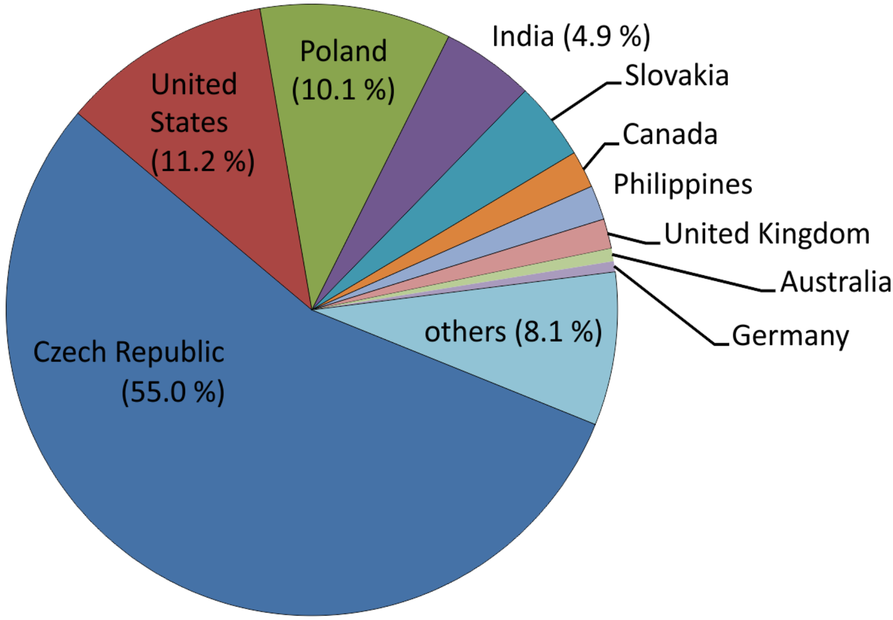

Fig. 4. Geographical distribution of visitors from January 2014 to June 2015 (all Collections and languages together).

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 LAB[1] 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 Collaboration[2], 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

Woithe, J., Keller, O., Feistmantl, A., Jende, K., & Schmeling, S. (2016). Learning Particle Physics Using Timepix-Based Pixel Detectors at CERN S'Cool LAB. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 135–142). European Physical Society.

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

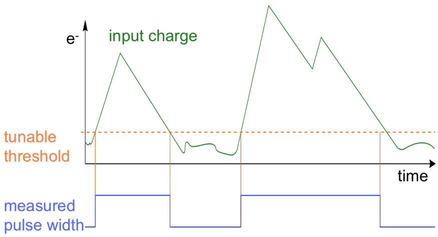

Fig. 3. Illustration of the energy measurement mode of Timepix. The time period in which the input charge stays above the threshold setting is proportional to the deposited energy.

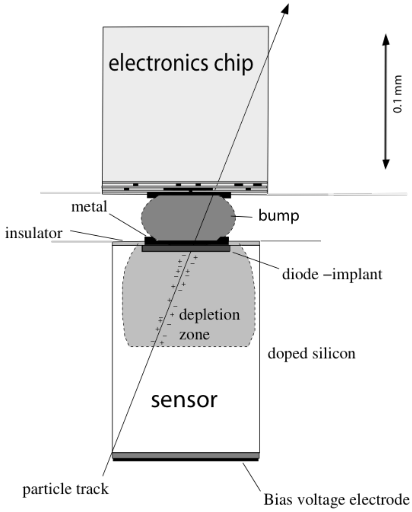

Fig. 2. Cross section through one pixel of a hybrid pixel detector with a particle track (reprint from Rossi, 2006).

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 x 1.4 cm2 and hosts 256 x 256 pixels, which results in a size of 55 x 55 μm^2 per pixel. Depending on the sensor and the bonding process, a certain minimal energy sensitivity of

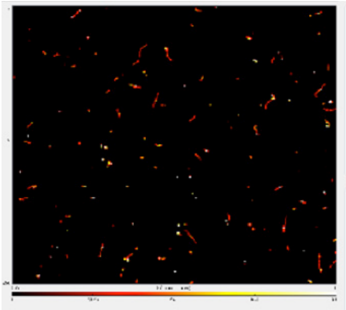

Fig. 4. Screenshot of a background measurement (35 min) with an MX-10 pixel detector and Pixelman software. The colour map represents the amount of energy.

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

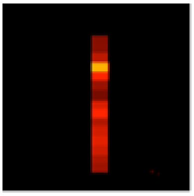

Fig. 5. Snapshot of “straight track” shape (muon candidate).

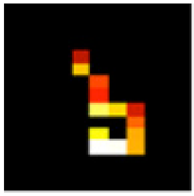

Fig. 6. Snapshot of “curly track” shape (beta candidate).

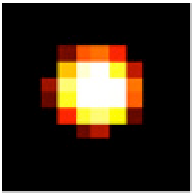

Fig. 7. Snapshot of “heavy blob” shape (alpha candidate).

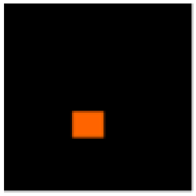

Fig. 8. Snapshot of “dot” shape (gamma candidate).

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

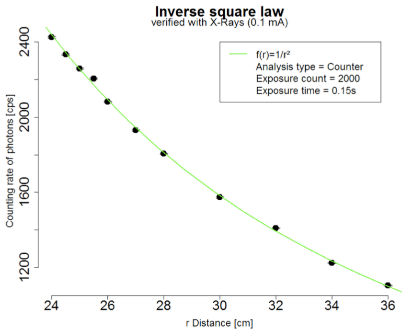

Fig. 9. Inverse square law.

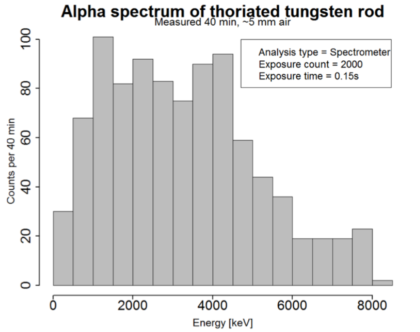

Fig. 10. Alpha spectrum of thoriated tungsten rod.

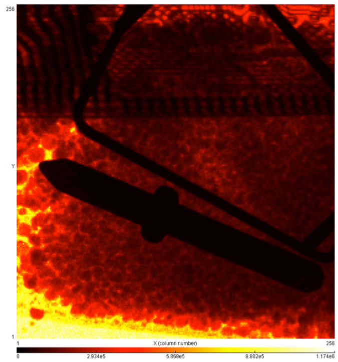

Fig. 11. Radiograph (solder pin, staples, salt grains, and memory card).

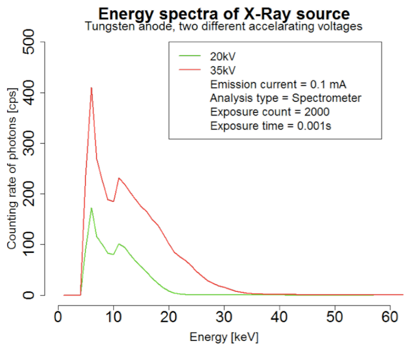

Fig. 12. Energy spectra of an X-Ray source (tungsten anode).

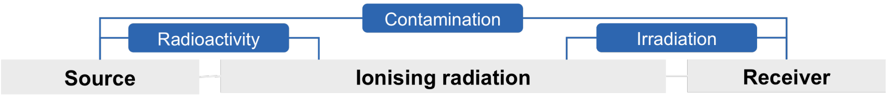

Fig. 13. Concepts associated with ionising radiation (Millar, Klaassen, & Eijkelhof, 1990).

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.

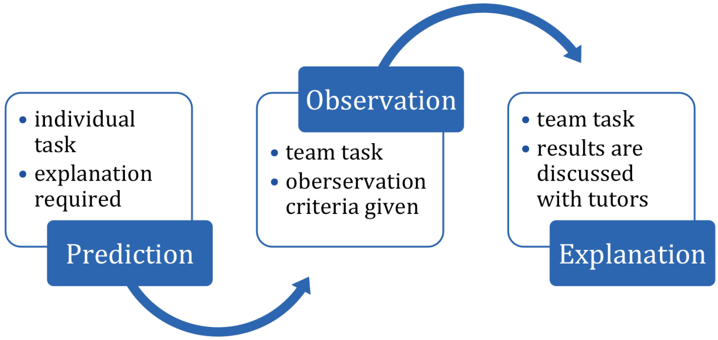

Fig. 14. Prediction-Observation-Explanation cycle in S'Cool LAB.

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.

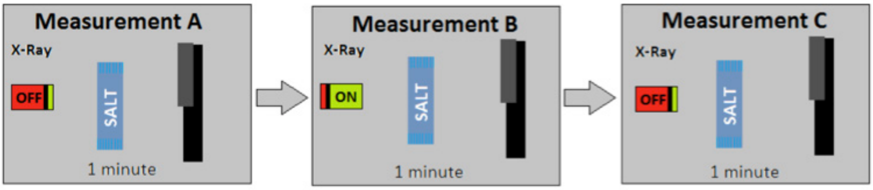

Fig. 15. Measurement schedule for POE task "Irradiation vs. Contamination" in S'Cool LAB. Students are asked to compare the number of particles measured by a pixel detector in A and in C.

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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Design and Create Your own Hologram

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One of the most interesting problems of the International Young Physicists´ Tournament in 2014 was called „Hologram". In this problem, students had to create their own hologram with the letters „IYPT". Creating a 3-Dimensional figure was supposed to be done by making scratches on a plastic sheet.
While working on the scratches, we came to understand holograms more. Our technique gave us a good opportunity and the motivation to get a better look at high school level impression of this interesting area of optics. In the next pages we will show how Hungarian high school students were working, modelling, understanding, designing and creating holograms – and meanwhile doing physics.

1 Photo- or holography

Our article features a special type of hologram, so at the outset we have to clarify in a simple way what a hologram is.

We don't only see holograms in laboratories, but in our everyday life as well. Probably one of the most recognizable of these is the security hologram, for example those which can be found on credit cards. Observing these, one can clearly see that the image changes depending on the angle at which one views it. These holograms retain their colour if moved only horizontally. However, if they are moved vertically, only their colour changes. These holograms are called rainbow holograms. We are going to discuss this type of hologram because this can be taken into schools and is similar to our holograms.

In physics class we learn how pictures are made and how to interpret them, but what is the difference between photographs and holograms? Perhaps one of the biggest differences is that the image created by holograms changes depending on the angle of view. Some images can only be seen from certain angles, while from others, they cannot be seen or only partially so. Not only can holograms create two dimensional images, but three dimensional ones as well. Photos are mainly made (and are viewed properly) white light. However, in the production of holograms, lasers are mostly used. Furthermore, some holograms are only visible under laser light. Thanks to how holograms are made, they have a special propriety: if we cut the recording (photographic) plate into pieces we may still be able to see the whole image (as every part of the recording plate has information recorded of the object thanks to the optical interference of the two parts of the laser beam).

As we mentioned before, holograms are mostly created with lasers. The laser beam is divided and a beam is directed onto the record plate, while the other beam is guided to the object to sample it as shown in figure 1.

The beam is reflected from the object, which creates an interference pattern on the recording plate due to the superposition of the two parts of the laser beam. One can observe constructive and destructive interference. The interference pattern is recorded on the recording plate because it is made of light-sensitive materials, such as silver halide.

D'Intino, E. Á., Pham T., L., & Hömöstrei, M. (2016). Design and Create Your own Hologram. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 143–150). European Physical Society.

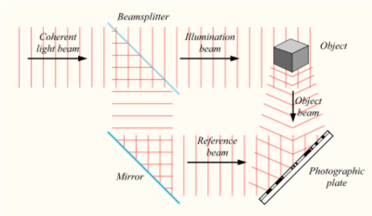

Fig. 1. The production of holograms.

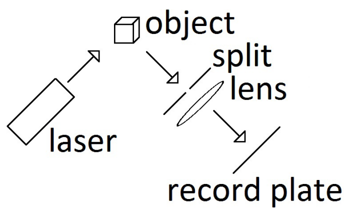

Fig. 2. The production of the Benton-hologram.

The smaller the sensitive particles in a compound, the better the resolution of the image. We can see these holograms using light sources similar to the laser during its production. The holograms are created in a dark room using lenses and mirrors with predetermined exposure times and precise laser control.

To be able to categorize the holograms by the creation process, there are three properties to take into consideration. Once we've understood the main types of hologram it is easier to see that in some way holograms may be able to create in the school.

I. Phase and amplitude modulation holograms: amplitude holograms determine the amount of light passing through the material, which is defined by the interference pattern on the record plate. Phase holograms use the thickness of the plate and/or the refractive index of the compound.

II. Thin and thick holograms: For thin holograms, the thickness of the recording plate is comparable to the wavelength of the illuminating light during production, while for thick holograms the plate thickness is much greater than that. An example of thin holograms is the one used on bank cards, where the depth of the image is not too big. On the other hand, the depth of images of thick holograms is much greater.

III. Transmission or reflection holograms: this distinction depends on the position of the light source. If it is on the same side of the plate as the observer it is a reflection hologram. If the light source is on the other side, the hologram is a transmission hologram.

The rainbow or Benton hologram is a special type of transmission hologram. The white light used for production goes through a horizontal slit to avoid the vertical parallax (figure 2). This way if the hologram is moved up and down only the colour of the image changes due to the change in wavelength. On the other hand, if the displacement is horizontal, the image changes and the colour remains the same. If the hologram is on a reflective surface the hologram is a reflective hologram. This is how holograms are created and how they work on credit cards.Illuminating a rainbow hologram with monochromatic light results in the original image being displayed, which can be seen through the slit. In white light one can see the whole image, because its components show different parts of the image.

2 Homemade holograms?

Holograms are generally made with lasers and complicated processes are required. The question arises: can we simply make a hologram at home or in school? Of course we can! We just need a compass and piece of stiff plastic (we used Plexi-glass) that is either black or painted black on the backside. In addition to this, we need manual skills to create a simplified version of the Benton hologram. Essentially, we make scratches with the compass on the sheet of plastic. The radius of the circle made by the compass, the length of the scratch and the position all play important roles in creating the image. This procedure makes a similar interference pattern to the Benton holograms, but it is a simplified version (figure 3).

At a given wavelength, due to the mapping of the lens, an interference pattern will form on the recording surface. We only make some of these scratches; the more scratches that are etched on the plate, the greater the resolution. Each arc corresponds to one pixel of the image and is centred around that point.

Fig. 3. The structure getting simpler.

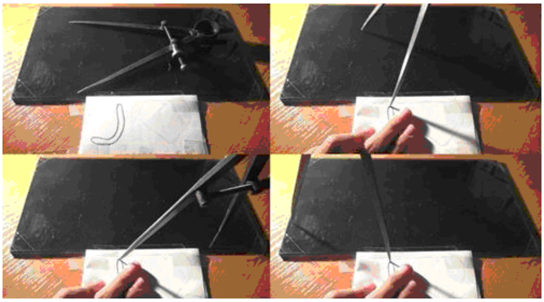

Fig. 4. Making the scratches. Creating a real hologram of a letter „J".

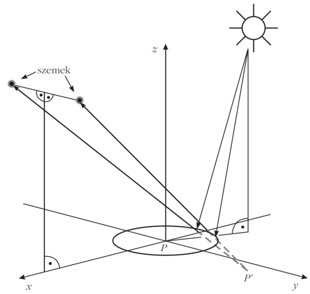

Fig. 5. Light reflecting from a circular scratch.

First of all, let's take a closer look at the scratching. To create a two dimensional image behind the plate we have to invent a figure. We demonstrate using the letter J (see figure 4.).

As we are only able to create holographic points and not lines, we need to break the original image up into points. The more points we draw around, the better the resolution of the holographic image of the letter. We then have to draw circles around every point of the letter without changing the radius of the circle. The radius can be chosen as we wish, however it is advised to be greater than the height of the original letter so as not to overlap with it. The change in radius only changes the depth of the holographic point below the surface of the plastic, but we will return to this later. We have to be careful, because if the scratches are too deep we will ruin the reflective surface of the plastic. The metal compass is heavy enough and thus we do not need to push down on it while scratching. On a sunny day or in a dark room with a point source of light, we will be able to see the hologram. The position of the image depends on the visual angle and the situation of the light source. The image may suffer distortion. How is the image formed?

One whole circle - whose centre is the point of which the holographic image (two points) will be created - scratched into the plastic determines four points from which light reaches our eyes. There are two on the side which is (*a*) closer to the light source (depicted in figure 5) and another pair on the (*b*) opposite side.

These two points at (*a*) reflect the light giving a reduced image behind the plate, while the other two points (*b*) yield a magnified image in front of the plate.

Each of these points reflects the light to one of our eyes. For a pair of points (pairs *a* or *b*), one of our eyes will see one point and the other will see the other of the two points making up the given pair. Thus, we will see one holographic point for each pair. The *b* type image point is where the paths of reflected light meet, while in the case *a,* we have to extend the paths to get the point of intersection (figure 5) as the point we see. The figure shows only the case where the light comes from the front. It is interesting to consider what would change if the light comes from behind the viewer!

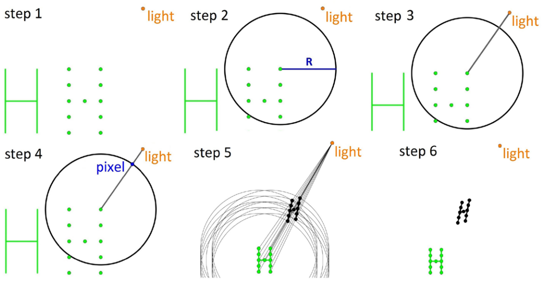

Fig. 6. Modelling in GeoGebra.

Fig. 7. The homemade hologram.

3 Design of holograms with GeoGebra

Although the procedure of scratching holograms is easier than using a laser, it is still time-consuming work. For this reason, we designed our holograms before we created them. The basic idea of the design came from two students at Berzsenyi Dániel High School, Bálint Kaszás and Zénó Madarász. To present the procedure we will show a design of a letter *H*, using GeoGebra which is downloadable for free from the website geogebra.org.

First, we have to decompose our figure into points, the more points, the better the resolution of the image (figure 6, step 1). We then draw a point, which will act as the *light* source. We will be able to see a simulation of the movement of our hologram by moving this point. Select one of the points as the centre of a circle with a radius of R (figure 6, step 2). It is advised to choose the R radius greater than the height of the figure, to prevent them from overlapping.

Then connect the centre of the circle with the point source of light (figure 6, step 3). Their intersection is the holographic point which we will see on our real hologram, so define a point at their intersection (figure 6, step 4). (Note: If we use a line going through the centre of the circle and the point of light, we will get two intersections which are the two holographic points mentioned in the 'How is the image formed?' section. The one closer to the source of light and gives the reduced image, while the further away is the magnified one. Here we are only using the points a - the points closer to the source of light.) There is an option in Geogebra to hide the functions (plane curves) we do not need, so do that with the circle and the section we used (figure 6, step 5). This solely serves to make editing and viewing easier and less chaotic.

Now we apply the described procedure to every single point of the figure (figure 6, step 6; figure 7 shows the hologram in real life). When finished, we can test our hologram by moving the *light* source.

4 HolograMagic

The previously described design was just a basic figure one can make. We can also make more complicated designs, including for example a square around our *H*. There are two options to make this. We can make it on the same radius, so that the letter and square move and distort together. Here we do not need any different knowledge from what was previously presented. But what would happen if these two figures had two different radii? Their paths would be different, so we could make a square that functioned as a little window (or as a little wall).

To have the image of the two figures overlap despite having different radii, one of them must be dislocated by a vector *u*. Let us move the *H* above the square (figure 8). The radii of the circles around the points of the square remains *R*, while the radii of the circles around the points making the *H* will be: $R - u = r$.

We cannot scratch whole circles around points of the *H,* however, because if we do, the holographic image of the letter H will be seen under every angle and it will not disappear outside its

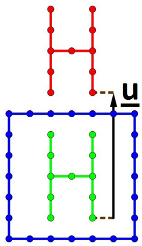

Fig. 8. The letter 'H' displaced by the vector u.

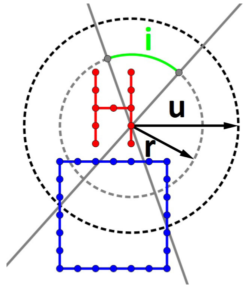

Fig. 9. Determining the arc.

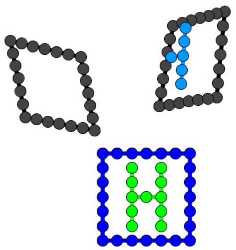

Fig. 10. The letter 'H' behind the window.

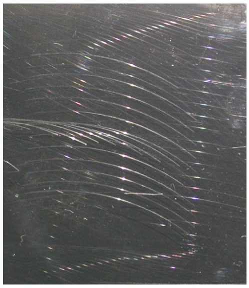

Fig. 11. The hologram in real life.

window (the square). This is why we have to make the scratches only when the *H* is inside the square or only outside of it. We discovered a way to find where the scratches should be.

First, we need to put a circle with radius *u* around one point of the translocated H. At this point, we draw a line connecting the centre of the circle and each intersection of the circle with the sides of the square. Then we need to add another circle with the same centre point, but with a radius of *r*. The arc between the intersections of the lines and the circle with the radius of *r* will determine the points in the square (in figure 9 it is marked with i). The intersection of this arc and the line section connecting the centre of the circle (arc) and the light source is the holographic point we will see. If the arc and the line section does not have an intersection, then there will be no holographic points to be seen, meaning the H 'disappeared' outside the window. Applying the same process to every point of the figure *H*, we will get a hologram like the one in figure 11.

5 The task: IYPT label

The competition required a hologram that contains the letters of the contest. Our main goal was to create a cube with the letters on the sides. Some steps are similar to the previous method.

First of all we need two identical squares and one of them (red) has to be displaced by a vector *u* (figure 12). The circles with radius *R* around points of the nondisplaced (blue) square will give us the holographic points of the front side of the cube, while circles with radius *r* around points of the displaced one (red) will give us the points of the back side of the cube. The radius (*r*) of the circles around the points of the displaced (red) square has to be smaller than *R* by the length of the displacement (*u*). ($R - u = r$) This way, the displacement defines the depth of the spatial shape because one of the squares moves less than the other when the light source is moved. This creates the illusion of space. As the object we want to create is a cube, the length of the displacement (the depth of the object) has to equal the length of the sides of the cube.

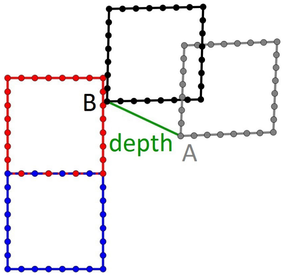

Fig. 12. Constructing the cube.

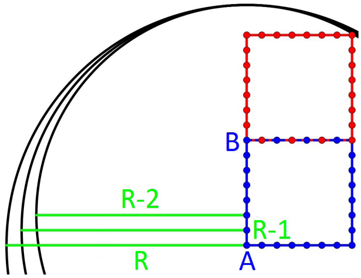

Fig. 13. The radii of circles to form the lateral sides.

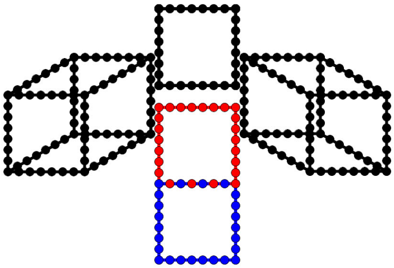

Fig. 14. The three-dimensional cube.

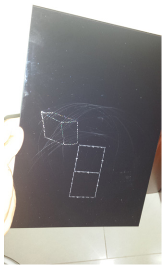

Fig. 15. The three-dimensional cube.

Drawing the lateral edges is more complicated than the facing ones. Let us use the variable we introduced previously, R – the radius of the shape that was not translocated, u - the displacement vector and r for the displaced figure. We select two vertices which are to be connected: A, which will be the lower front left vertex on the cube and B, which will be the lower back left vertex. To create the edge between the two vertices (points A and B) we start by drawing an arc with a radius of R around point A (figure 13). Let us define the distance between two neighbouring points we want to draw a circle around as a unit. We then take the point that is a unit closer to B from A on the side of the first (blue) square and use that as the centre to draw an arc with a radius of R-1. After each step of a unit towards point B, the radius of the circle drawn around that point must be reduced by 1 unit until we reach point B, where the radius of the arc is r. After repeating this for every pair of vertices (4 in total), we obtain a cube (figure 14). What makes this special is that a holographic image of a spatial shape (cube) was created from a two dimensional figure (figure 15).

Exactly four sides of the cube can be seen, which fits the task perfectly. We can see only three sides of the cube at once, however at any given angle we can see the side facing the cube. We already know how to write onto the front side of the cube (the same way we draw the edges of the front side), but what about the lateral and upper side? The letter we will use as an example will be a *T* situated on a lateral side of the cube. First we have to locate where we want the letter on the lateral side to be positioned. We decompose the image into points as usual and find the depth (distance from the front side) and height (distance from the bottom side) of a given point of the letter (figure 16a). For example, we start from one of the frontal corners and the depth of the point is three units, so we reduce the radius *R* by three units and step up three units (figure 16b). Then if the height is three as well, we make three steps again towards point D (figure 16b) and now we make the scratch (with the calculated R-3 radius and centre point we stepped on). This enables us to write on the lateral sides. The writing to the upper side is similar to the previously shown method. We have to find the horizontal position (distance from

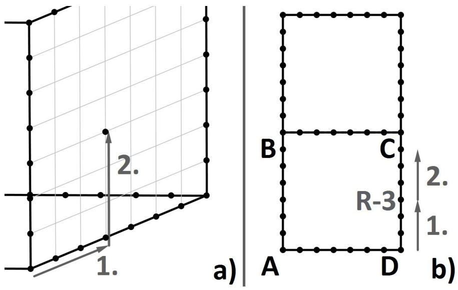

Fig. 16. Determining the position of the selected point.

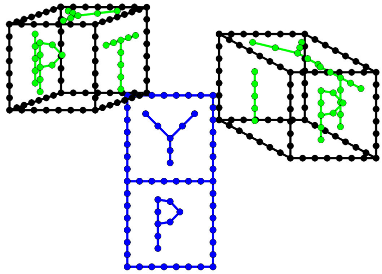

Fig. 17. The IYPT cube.

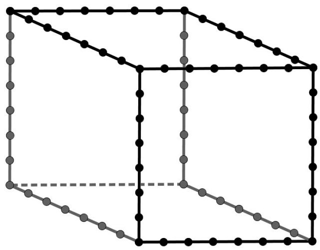

Fig. 18. Lines to not to draw.

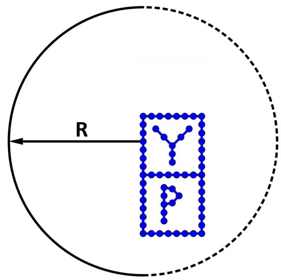

Fig. 19. Arc of the side edge.

the left side of the cube) of a given point of the letter then search the depth of it to make the scratch. We reduce the radius *R* by the depth of the point while stepping towards the rear side and then step the horizontal distance in units from point B to C and we can make the scratch.

To sum up how to write on the sides of the cube, all we have to know is two pieces of information: the distance of a point of any letter (shape) from the relevant side of the cube (lateral, bottom or top) and the depth of the point which is measured from the front side of the cube. The distance mentioned before is the distance we have to step away from the relevant vertex. Meanwhile the depth is the amount we have to subtract from the original radius R to get the new radius as well as step towards the vertex belonging to the back side of the cube to make the scratch.

Once we have finished we get something like what is shown in figure 17. As we can see, one thing ruins the image: we are able to see the parts of the cube which in real life are hidden in the case of a solid non-transparent cube.

To make it realistic we classified the edges of the cube (figure 18). The black lines must always be present, while the dashed edge is never scratched. The grey edges are visible only in given domains. For example, figure 19 depicts where we have to make the scratch and where not to do so when scratching arcs for the right rear edge of the cube. We only need to make the scratch until the intersection of the circle and the vertical line of the sides of the squares as passing that point the cube will cover that edge from sight. Arcs for points of letters on the right side will also be scratched until that line. Similarly, the rear left and bottom left edge and the letter on the left side will also be scratched only until the line of the left vertical sides of the squares.

With this method we can get the three dimensional cube with the letters I, Y, P, T on the sides. As we look at it, we can see that its movements are the same as if we saw a similar, real cube in front of us: The sides disappear and appear when needed and the edges that would be hidden are not seen (figure 21).

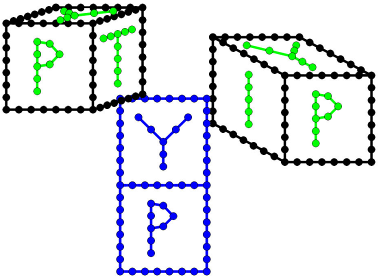

Fig. 20. Modelling an IYPT cube in GeoGebra.

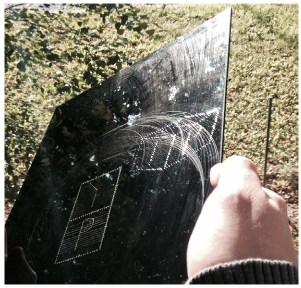

Fig. 21. Real hologram of an IYPT cube.

6 Are these images holograms?

There is an ongoing debate as to whether the scratch hologram can be considered real holograms or not. Taking the properties of the image we see into consideration, we believe it is. If we look at it from different angles, the image will also be different: some points disappear, others appear (e.g.: the letter H with the window/wall, the IYPT cube). Moreover, the scratch hologram actually uses a two dimensional mapping of a virtual three dimensional object to create the image of the three dimensional image. The scratch holograms only differ from traditional holograms in the fact that they use a virtual object, whereas the latter use real objects. However traditional holograms also use two dimensional mapping (the recorded interference pattern) to create a three dimensional virtual image of the original object.

7 Conclusion

We created scratch holograms as simple as the letter *H* and as complex as the IYPT cube. A method was developed to have points appear and disappear as desired. Using the program GeoGebra, we made a simulation of the holograms and thus we were able to make a three dimensional image (the IYPT cube). This combined the techniques that change the depth of the virtual points and those that allow us to control the range where a point can be seen. We have also proven its status as a real hologram and investigated the colors of the points due to diffraction.

This project was a great opportunity for students to learn about holograms in detail while creating their own scratch holograms. Aside from the interesting methods, students can learn about the most important phenomena of geometrical and physical optics. The program GeoGebra we employed for the simulation is widely used in mathematics lessons and was an essential part of creating and modelling scratch holograms. Using the knowledge and motivation students have for computers and interesting phenomena, we believe this case offers a good opportunity to teach and learn physics.

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Using Videos to Develop an Understanding of Measurement Uncertainties

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Through the targeted use of online-videos, it is possible to improve the process of learning and teaching in schools and universities. However, the potential of the medium can only be exploited, if the videos are well produced from an educational point of view. This requires a broad understanding of the students' needs and their usage of videos in a specific learning scenario. In this paper, we present an instrument that is able to give detailed insight into students' video usage and thought processes during task solutions. The instrument was successfully tested in a study investigating how students use videos to solve simple data analysis tasks. The benefits of the instrument are demonstrated in the analysis of two task solutions.

1 The Need for Educational Videos in Adapted Learning Scenarios

Over the last few decades, the use of modern technology has changed our everyday lives. As a result of this rapid development of digital tools, many new ways to learn and teach have come about (Handke, 2015). Schools and universities nowadays need to adapt themselves to these new conditions and to a new generation of students. This conclusion stems from the fact that traditional methods of learning and teaching don't fit the reality of today's learners. Moreover, there remains the ambitious hope to improve and optimize students' education with new media (Iske, 2003).

Online-videos represent one of the most common multimedia tools. Especially in Germany, the usage of videos has increased consistently within the so-called Information Age. Nowadays, 98% of the 14-29 year-olds living in Germany use online-videos with a proportion of 54% of this target group using online-videos daily (Kupferschmitt, 2015). Thus, it's safe to say that almost every student in school and university is familiar with online-videos. Based on stated data it appears worthwhile to investigate if videos are suitable for enhancing learning and teaching environments, as they are widely accepted and well-liked. Additionally, videos offer the advantage of addressing learners' visual and auditory channels simultaneously and thus seem to be superior to traditional media like text (Handke, 2015). Apart from the benefits for learners, videos also seem to be attractive for teachers and lecturers. The production of simple videos is easy and can be done with a cell phone, webcam or low-cost camera in a few minutes at home. It seems to be a convenient way to create educational material in a comparatively short period of time without too much effort. Furthermore, videos can be easily distributed via the internet to ensure high availability of learning resources (Schön & Ebner, 2013). The present dominance of educational video platforms and *"Massive Open Online Courses"*, called MOOCs, underpins the idea of videos as an easy to use and effective learning tool (Schulmeister, 2013).

The enthusiasm for videos described above is primarily built on a cursory examination of the topic and doesn't take into account scientific results concerning learning with this type of media. If these findings are reconsidered, then limitations of new media in general need to be accepted and respected: Better learning outcomes never result only from the

Hamacher, J., Erkelenz, J., & Heinke, H. (2016). Using Videos to Develop an Understanding of Measurement Uncertainties. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 151–159). European Physical Society.

usage of new media. The important driving forces behind enhanced learning and teaching environments are improved educational scenarios and teaching methods, which take advantage of the new resources available (Kerres, 2003). For this purpose, the usage of educational videos is mandatory. Videos of this type result from critical engagement with the information to be conveyed, appropriate ways to mediate this information, the knowledge of specific needs of the target group and the best-possible match to the learning scenario in which the videos should be used (Handke, 2015). These criteria alone, however, are not enough to ensure an improvement in learning outcomes. On top of a high quality video production, an encouragement of students to actively work with the video contents is essential (Mayer, 2005). While watching videos, learners often tend to take a passive role, which makes it harder for them to handle large quantities of information. As a consequence, they usually have difficulties in memorizing contents shown due to their limited cognitive capacity. To tackle this problem, different measures are recommended: First, it is crucial to give viewers full control over playback speed, so that they can decide by themselves how fast a video is played and if they want to see passages again. Secondly, videos can be enriched with additional control options, such as a table of contents or markers to structure videos' information and to enable viewers to easily select which parts of the video they want to see (Merkt, 2015). Thirdly, it's useful to provide learners with further supporting material besides videos to either deepen their engagement with contents or to test their acquired knowledge (Handke, 2015). In general, the usage of videos should always be considered a highly specialized part of an entire learning scenario, where the videos fulfill a precise task in the whole learning process. Thus, videos need to be well prepared, and produced and deployed from an educational point of view to reach these goals.

In this paper, we present, conceptually, a means to integrate videos in a new approach to convey measurement uncertainties in an introductory physics laboratory at RWTH Aachen University. Furthermore, we focus on the introduction of a method of analyzing students' video usage during task solution, which opens up detailed insight into students' work processes. Based on these data, it will be possible to adapt videos to achieve a greater compatibility with the needs of the students.

2 Benefits Through Videos for an Understanding of Measurement Uncertainties

The execution of experiments and measurements is an essential cornerstone of scientific progress in every natural science. Thus, students at university need to build up experimental skills and a solid knowledge in the field of data analysis to meaningfully interpret measurement results (Welzel et al., 1998). For this, students have to manage and assess the importance of measurement uncertainties, a task which the majority find difficult and unenjoyable (Hamacher, Erkelenz & Heinke, 2015). In physics education, the first significant involvement with measurement uncertainties commonly takes place in introductory physics laboratories. But as studies in different countries indicate, most students are not able to take measurement uncertainties correctly into account and can't integrate them into their calculations and argumentations in a scientifically accurate way even after attending a whole laboratory course (Séré, Journeaux & Larcher, 1993; Deardorff, 2001; Heinicke, 2012). An important reason for this is that literature on the conceptual understanding of measurement uncertainties can be difficult to find. This fact is exacerbated by the widespread application of frequentist formalism and terminology on handling measurement data (Lippmann-Kung, 2005; Buffler, Allie & Lubben, 2001). These topic-related problems are accompanied by a further structural problem in common laboratory courses, where majority of students' engagement with measurement uncertainties takes place at home while they are working on their lab protocols. An analysis of this work phase reveals that students spend a large amount of time, on average seven hours per protocol, carrying out their data analysis. During this time, students typically don't have the chance to pose questions to tutors, and must find answers to their questions for themselves (Schwarz, Effertz & Heinke, 2013a). Since formalism and terminology on the topic of measurement uncertain-

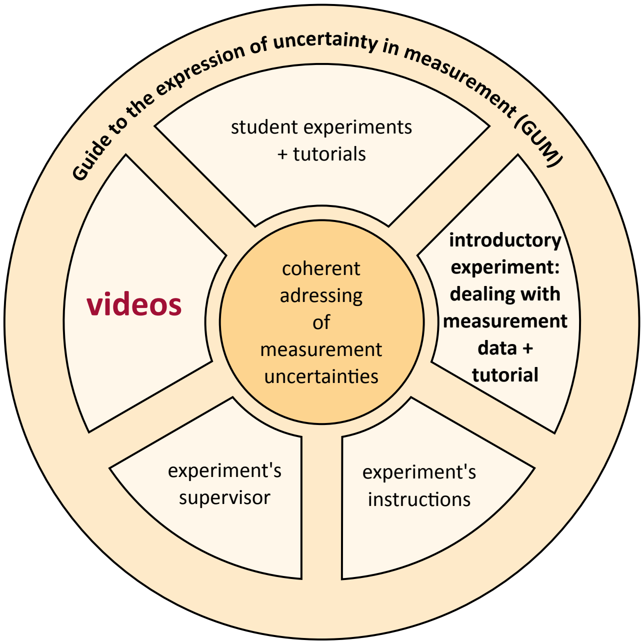

Fig. 1. Components of a revised physics laboratory to convey measurement uncertainties in an introductory physics laboratory, which is applied for biology and biotechnology students at RWTH Aachen University..

ties aren't used consistently in scientific literature and a lot of differences and even contradictions exist (Heinicke, 2012), this constellation makes it difficult for students to build up a deeper knowledge about the subject. To summarize, students spend a huge amount of time on the important phase of data analysis at home without appropriate supporting tutors and material, and they all too often fail to sufficiently achieve the desired level of competency on measurement uncertainties.

All these mentioned problems were also observed in different physics introductory laboratory courses at RWTH Aachen University. For this reason, a new approach to convey measurement uncertainties is under development to improve students' learning environment. It will be applied first for an introductory physics laboratory for biology and biotechnology students. Figure 1 shows all components of this revised physics laboratory. The most important aim of this new concept is to ensure a coherent addressing of measurement uncertainties throughout the whole laboratory. For this reason, several changes to traditional courses were made, the most important being:

- First of all, the handling of measurement uncertainties will follow the rules and terminology of the international norm *"Guide to the expression of uncertainty in measurement"*, called GUM, to provide the students with technically consistent formalism (JCGM, 2008).
- Secondly, the introductory experiment, which focuses solely on dealing with measurement data, will be revised and shift its focus to more cooperative learning methods to engage the students in discussions about the concept of measurement uncertainties.
- Moreover, short and target-group specific online-videos will be produced conveying basic skills in data analysis and measurement uncertainties in order to support students in their work while at home.

A detailed discussion about the whole concept with explicit presentation of all novelties can be found in Hamacher, Erkelenz & Heinke (2015). Hereafter, the focus is on justification for the use of videos in this learning scenario.

Laboratory courses at RWTH Aachen University and other universities typically cover up to 200 participants per course per semester. Individual tutoring for every student can't be realized under these circumstances on a regular basis, especially not for their work at home. Online-videos match important requirements to reach out to all students in this situation, as videos are both easy to distribute by course coordinators and easy to attain by students via internet. Furthermore, the topic of data analysis offers good opportunities to split up the whole content in modular-based learning units, which can be presented in videos with a maximum playtime of 8 minutes. Videos also offer the potential to prepare the often abstract contents in a more appealing, illustrative and target-group specific way. Despite the many reasons for the production of videos, whether the use of video tutorials results in a noticeable increase in students' data analysis skills must still be investigated. Hence, Effertz et al. (2015) carried out a study (N = 24) with first-generation videos produced at RWTH Aachen University. In the study, students had to perform simple analyses of measurements, as typically found in everyday laboratory practice. The videos consisted of simple produced screencasts in which a tutor talked over his work with pen and paper. An example screenshot can be seen in the upper part of figure 2. It could be shown in the study that students, who were allowed to use videos during their task solution, achieved significantly better results concerning completeness and correctness of their solutions compared to students who were without access to the videos (Effertz et al., 2015). The students reported that they felt a decreased difficulty of given tasks due to the video usage. A final questionnaire revealed that a broad majority of students approved of the videos as a useful learning tool. Based on this study, it was decided to continue with the work and produce more elaborate videos.

3 Process Diagrams and Think Aloud Transcripts

As mentioned in chapter one, a thorough analysis of the needs and habits of the target group is necessary to produce videos that reach their highest potential in learning scenarios. For this reason, an instrument is needed which permits analysis of a considerable body of content-related and work process-related data on students' behavior during data analysis. As will be shown below, the combination of process diagrams and think aloud transcripts in addition to written records of the students is suitable to tackle this task. To this end, an analysis of process diagrams gives greater insight into process-related data while think aloud transcripts produce a deeper understanding of motivations and benefits due to the use of videos. The instrument was successfully tested in a usability study (N = 14) to analyze the use of videos in simple data analysis task solutions by students of biology. A set of four more elaborate second-generation video tutorials concerning data analysis (*"stating measurement data", "average", "standard deviation"* and *"measurement uncertainty"*) was used in this study. All video information was embedded in a short contextual description, and example calculations were executed next to important formulas and explanations. On the technical side, a speaker working with pen and paper was supplemented by the fading-in of short scenes from a real experiment, as well as texts and inputs on a calculator display to improve the videos. An example screenshot of the video *"measurement uncertainty"* is given in the lower part of figure 2.

The methodology used in this study can be seen in figure 3. One of the priorities of this study was to analyze how and why students used videos during their work. Thus, a design was chosen which enabled a comparison between the work of students with and without videos. The study began with a general introduction by a tutor including a short training of the *think aloud method.* The students were then asked to determine the result of a measurement containing 10 repeated readings using a calculator only. From this, the students had to use the *think aloud method* throughout the whole work process. After finishing, the students received a simplified feedback on their task performance from the tutor consisting of only whether their final result was right or wrong. Immediately afterwards, they had to work on a similar content-related task and again had to use the *think aloud method.* For

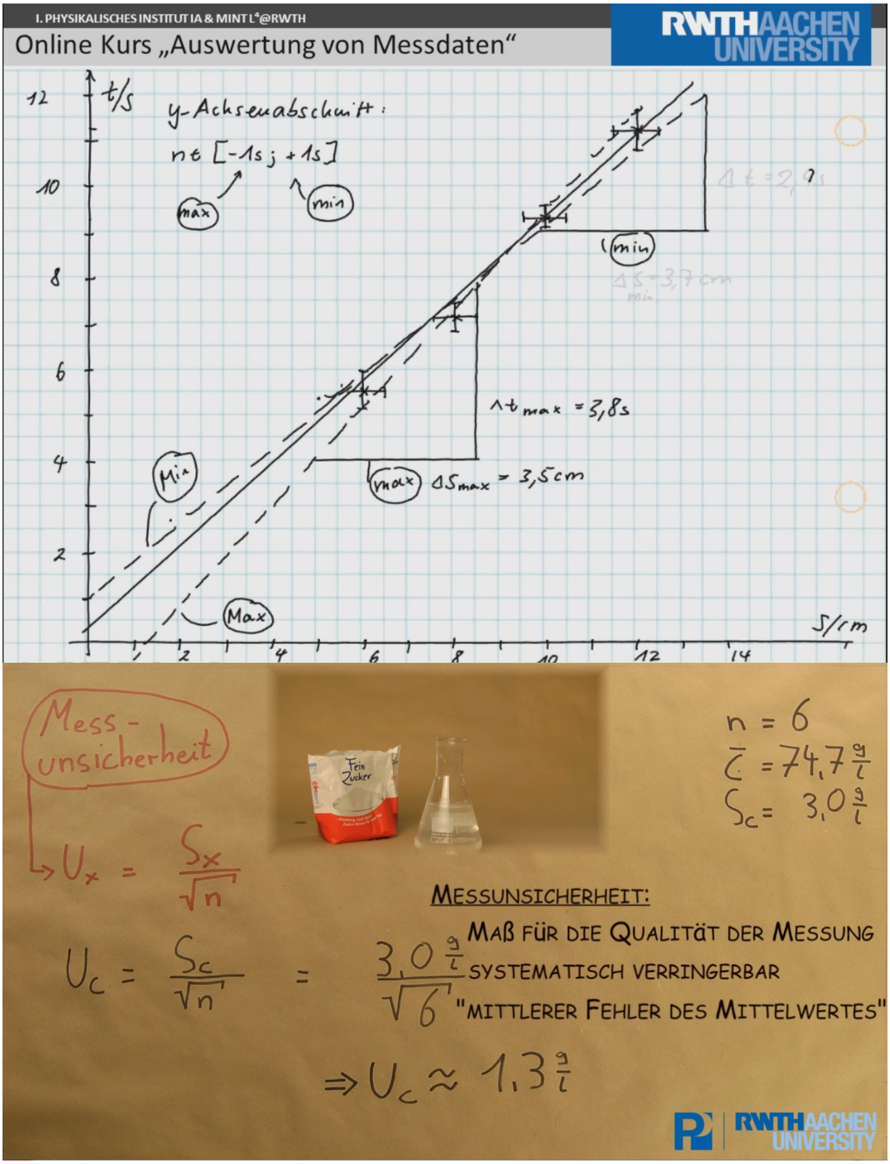

Fig. 2. Screenshots of videos used in different studies (upper screenshot: first-generation video; lower screenshot: second-generation video).

this second task, the students had free access to the set of four videos described above via a notebook. From this, they were free to use videos of their choice at any time during their task solution. The four available videos contained all important information to perform the task successfully. After finishing the second task solution, students were asked to fill in a questionnaire on their opinions on the videos. Students used a smartpen throughout the study to record both their spoken thoughts and the development of their working progress. In parallel, screen capturing software recorded all their clicking behavior on the notebooks while working on the second task (see figure 3).

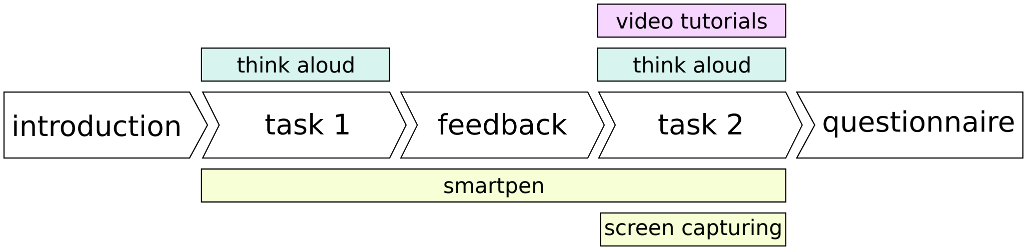

Fig. 3. Methodology of a usability study (N = 14) to analyze students' work without and with video tutorials during task solution.

The number of conclusive statements about students' data analysis processes would have been very limited and conclusions about their video usage would have been nearly impossible had the available data on the work process been restricted to the final written products of the students. However, the combination of the data from the smartpen and screen capturing software enabled process diagrams (see fig. 4 for examples) in which the video usage and progress of task solution can be resolved in detail for each student over time. Thus, differences between students' work processes can be seen by eye. Furthermore, it is possible to assess their handling of measurement data by analyzing their think aloud transcripts.

The power of the instrument is demonstrated by a comparison of the work processes of two selected study participants (A and B). The two process diagrams are given in figure 4. Key features of the diagrams are the colored boxes and ovals which represent phases of video watching and phases of task progression, respectively. They are plotted for all four videos separately. Here, each video has its own unique color and color grading, whereby every color grading represents a content-related section of a video. If a student doesn't start working in the specific content area of a video, a cross can be seen in the diagram. The end of a task solution is represented by a dotted line, while the total playtime of one video is visualized through a stripe over the video boxes. Triangles indicate moments when a student writes down information given in a video. If a student pauses a video and the last video image remains frozen on their screen, the video box in the process diagram changes its color to grey. Taking this encoding into account, initial similarities and differences between the representations of the two work processes in figure 4 are readily apparent.

Student A merely states an average as a physically complete result in task 1, whereas student B also includes a measurement uncertainty which isn't however based on a standard deviation. Both students need nearly the same amount of time to give a result. After receiving a feedback on an incorrect final result from the tutor, both students start to watch all videos in task 2. They choose the same order of watching and write down information from the videos. As opposed to task 1, both students now work on all relevant physical values for a complete result. The differences between student A and B concern the total processing time for the task, the length of video material seen and the general work style. While student A watches all videos until the end, student B does not finish watching even one single video. Additionally, student A doesn't start working on a solution until he has seen all videos, whereas student B starts to work right after he stopped his first video. From there on, student B switches constantly between video watching and task solution phases. The following obvious conclusions can be drawn from the process diagrams:

- Students A and B had different previous knowledge about stating a physically complete result.
- Both students watched all videos and tried to apply the knowledge from them to the given task.
- Both students chose a completely different way to use the videos in their task solutions.

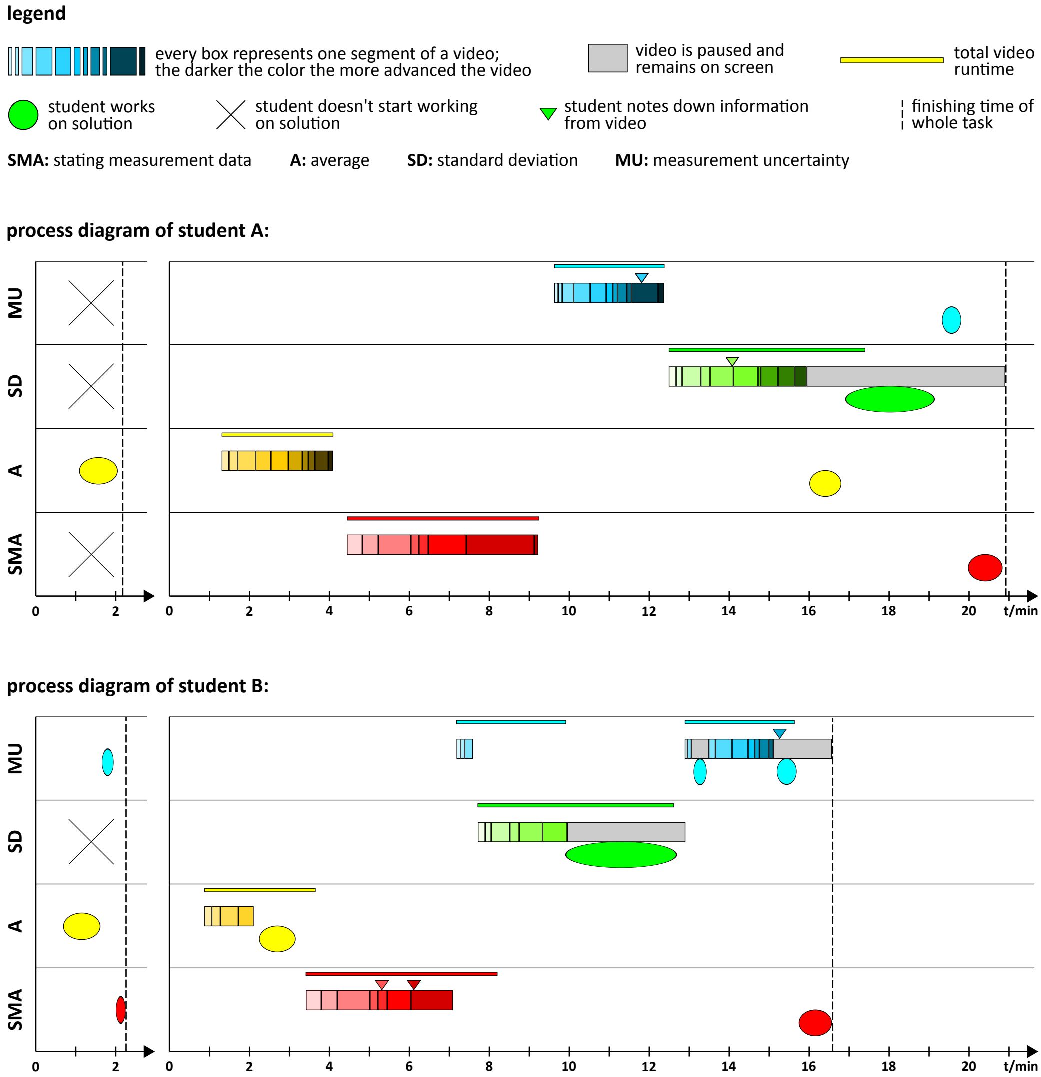

Fig. 4. Exemplary process diagrams for analyzing students' video usage during the solving processes of data analysis related tasks.

A more complete picture of the whole process of task solution can be accessed through a combination of data from the written products, the think aloud transcripts and the process diagrams. Both students were unable to give a correct result in task 1. However, the think aloud transcripts reveal a significant difference in their conceptual understanding of a physically complete result. Student A believed that an average alone (without a measurement uncertainty) is already a complete result. This is concluded from his explicit mentioning that he didn't see the need to state a measurement uncertainty as it was not requested in the task. In task 2, he still hesitated to calculate this quantity even after its necessity was explicitly mentioned in a video. Out of this misconception it is also possible to explain his video usage. After expressing that he had no idea what he did wrong in task 1, he started to watch the "average" video, apparently because the average seemed to be for him the only relevant quantity. As the video didn't help him to proceed, he continued by watching all other videos completely to gather all available information. Ultimately, he was able to choose the right approach with the help of the videos (although he miscalculated the standard deviation and ended up with an incorrect final result for task 2 as well).

As opposed to student A, student B already knew in task 1 that a measurement uncertainty needed to be stated. According to his think aloud transcript he just forgot how to calculate this quantity and thus made an estimate which explains his video usage. After double checking his average calculation via watching the "average"-video, he chose a very selective way to use the videos as he just searched for specific formulas to calculate the final result. After finding the formulas, he paused or stopped the videos and started to calculate the quantity discussed in the video. In using this strategy, he succeeded to improve his approach from task 1, but also failed to give a completely correct result. Reasons for that failure included his miscalculation of the standard deviation as well as a misunderstanding of a video's explanation on significant digits. Because of the latter, he didn't realize that there is a difference between the number of significant digits and the number of digits given after a decimal point. This underlines a severe misconception frequently observed even after students have finished physical lab courses (Schwarz, Effertz & Heinke, 2013b).

In summary, both students' overall task performances improved through the use of videos. The data for both students also underline the fact that videos alone are insufficient to guarantee a full understanding of the given information, a conclusion that is consistent with statements in chapter 1.

The various aspects discussed above represent only part of the information gained by the presented instrument. Nevertheless, the above factors already demonstrate that a combined analysis of written products, process diagrams and think aloud transcripts permits access to in-depth studies of the work processes of students, which can help to improve the production of supportive educational videos.

4 Summary and Outlook

Potential benefits of videos supporting the processes of learning and teaching were presented. Usage of videos in learning processes can succeed only if they are well-prepared and produced and deployed within a whole learning scenario. The production of supportive educational videos requires a deep understanding of students' specific use of videos in learning and working processes.

A new approach to deploy measurement uncertainties in introductory physics lab courses is under development at RWTH Aachen University. In this effort, online-videos should support students in the often difficult phase of data analysis at home and improve the learning outcomes in a field rife with serious misconceptions. Detailed knowledge about the usage of videos during data analysis is required to produce a set of suitable education-enhancing videos. For this reason an instrument was developed and successfully tested, that consists of a combined recording and analysis of written products, process diagrams and think aloud transcripts. The instrument also gives in-depth insight into students' working and learning progress in this way. This has been demonstrated for students tasked with determining a measurement result by repeated readings. However, the instrument is also expected to be suitable for analyzing more complex tasks as well as other learning scenarios which contain video usage.

Since a laboratory study design has been used in the present study, students' video usage during data analysis in real learning scenarios can differ from that observed in the study. This opens a research gap which is tackled by a study which is currently in preparation. This study will aim at the complete recording of the work processes of selected pairs of students during data analysis and protocol writing in a physics laboratory course. In this way, the students can use educational videos during their work at home. The findings of this study will provide further useful information for the production of supportive educational videos on the topic of measurement uncertainties and data analysis procedures.

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Towards Attractive Interactive Instructions for Practical Physics Laboratories

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This study is intended to develop attractive, interactive, multimedia-based instructions for physics laboratories in order to exploit the advantages of technology-enhanced learning in today's students' digital environment. These technology-enhanced instructions retain the same core content as their paper-based predecessors, but can be enriched by various multimedia tools, such as videos, simulations and Interactive Screen Experiments (ISE), enhancing the educational potential of lab instructions. Benefit for learning processes is expected due to both the multimodal and the potentially interactive nature of the media used in these instructions.
This article describes the design of interactive, technology-enhanced instructions, based on students' approach to real experiments. For this, students' experimental performance was analyzed in detail for an experiment on radioactivity utilizing Smartpen data. In addition to that, students' demands for interactive elements were asked in a survey. We expect that this user-oriented approach will bring a high acceptance among the students.

1 Approach

The experiment on radioactivity is part of a hands-on laboratory. The students (working in groups of two) are given a printed 5-page manual to read prior to the performance of the experiment. These manuals shall be digitalized and enriched by multimedia tools.

Defining interactive instructions is the first step of an iterative process in developing a new type of instructions, as illustrated on the right in Fig. 1. The same figure indicates that in the present study, there were two sources of empirical data for defining these instructions: a survey conducted with mechanical engineering students in the winter term of 2014/15, and a Smartpen study on the experimental performance of students for a particular experiment. The results of the Smartpen study and its implications for the instruction design are the main focus of this paper.

The survey consisted of a questionnaire with 125 student participants. It aimed at clarifying both the current availability of multimedia equipment for potential users of the interactive instructions as well as the user-requirements for these instructions. The survey provides general information that is important for the design of interactive, technology-enhanced instructions of experiments in practical physics laboratories. The survey data is expected to be specific to each user group, but can be generalized at least for different experiments in a physics lab for one user group (i.e. students of a particular study program). The results of the survey, which are only shortly presented in the second section, can be found in detail in ref. (Büsch, 2015).

At the same time, a Smartpen study was conducted in the summer term of 2015 on the topic of handling the experimental setup, and carrying out data acquisition and analysis for a specific experiment. This was done as an example for an experiment on radioactivity

Büsch, L., & Heike, H. (2016). Towards Attractive Interactive Instructions for Practical Physics Laboratories. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 161–169). European Physical Society.

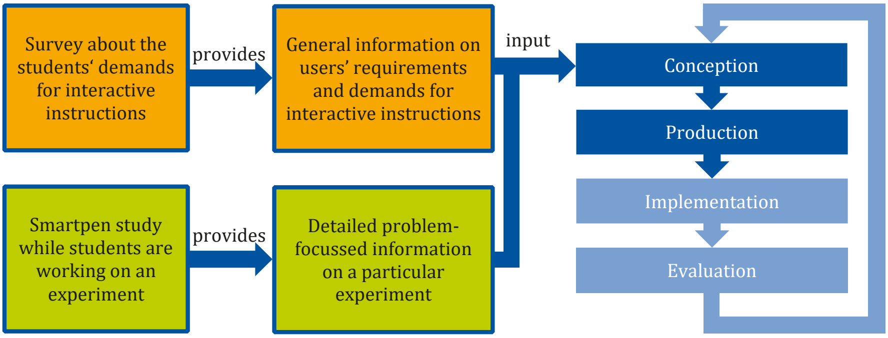

Fig. 1. Schematic view of the development process of the new interactive instructions.

providing detailed data on this particular experiment, as illustrated in Fig. 1. The study can be described as problem-focussed because the problems encountered while students performed the experiment itself and conducted data analysis were of particular interest. For this reason, in addition to documenting the students' actions with Smartpens, the tutor was also equipped with a Smartpen and a specially designed protocol form. While the students' Smartpens should provide a complete overview on the processes carried out during the preparation and execution of the measurements and the subsequent data analysis, the Smartpen protocol of the tutor is expected to focus on the problems which the students encountered during the experiment (including data analysis, too in our case). The collective Smartpen data can lead to a deeper understanding of the concrete experimental procedures and help to diagnose problems in the process. In this way, we follow a similar approach as reported by Fraß et al. (Fraß et al., 2014) who used a Smartpen study to substantiate the design of an ISE. Unlike this earlier study, the Smartpen data and its conclusions will be used in the study presented here. This is done not only for the design of a new ISE for interactive instructions, but also to provide meaningful input for the conception of the instructions themselves. This is supported by the problem-focussed approach implemented here for the first time by using an additional Smartpen and a specially prepared log form for the tutor. In this way, the interactions between students and tutor can be easily recorded and difficulties in the execution and analysis of the experiment can be determined in detail very efficiently.

2 Results of the survey

In the winter term of 2014/15, a survey was carried out with two goals. The first was to characterize the multimedia equipment available to a group of student users. The second was to describe the users' demands for interactive elements within the instructions. 125 mechanical engineering students participated in the survey during their third semester, a group that represented the future users of the instructions.

In the survey, the students were asked about their multimedia equipment. The results agree with the JIM study from 2014 (Feierabend et al., 2014) on the availability of digital media to young people between 12 and 19 years of age in Germany. Both the survey and the JIM-study reinforce the idea that the availability of students' equipment have been now met for the broad integration of technology-enhanced learning concepts in everyday learning activities at university.

Furthermore, the students were asked to rate 15 potentially helpful elements of interactive, technology-enhanced instructions to evaluate their expected usefulness in preparing and performing physical experiments in the laboratory courses. The rating was carried out on a four-stage Likert-type scale. Figure 2 shows the results for 6 such elements: ISE, simulations, videos on background knowledge and performance, questions from prelimi-

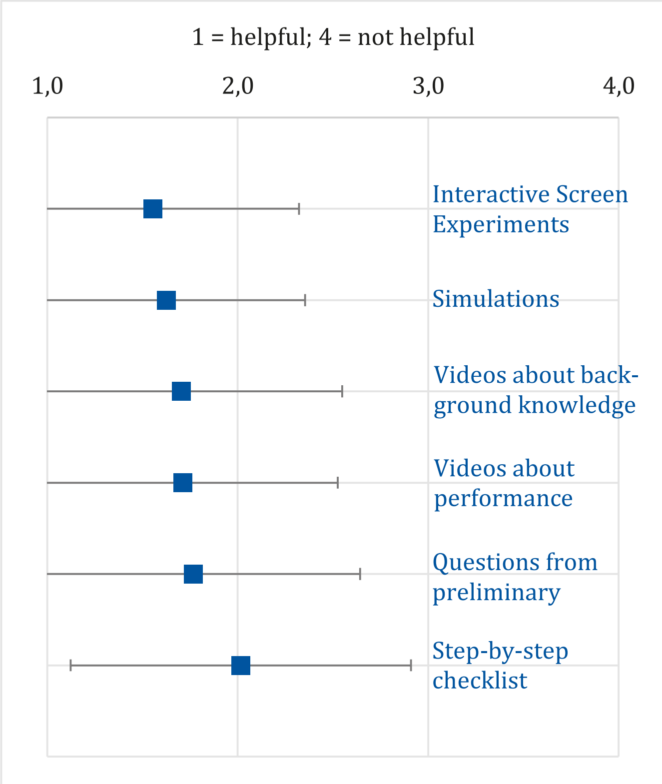

Fig. 2. Results of a survey where 125 students of mechanical engineering were asked about their expectations on potentially helpful components of interactive instructions for physical experiments.

nary discussion and a step-by-step checklist. All the elements shown in Fig. 2 were ranked positively by at least 75% of the students and were among the eight highest ranked options (see ref. (Büsch et al., 2015) for details).

Thus, the survey provides insight as to which potential elements of technology-enhanced laboratory instructions might meet with high acceptance among their future users. In this way, it provides useful information for the development of interactive instructions for various experiments for the use of bachelor's students of mechanical engineering. Whether students' demands differ clearly for students enrolled in different study courses must still be tested.

3 Smartpen study

The Smartpen study in question was conducted in the summer term of 2015. 33 students carried out an experiment on radioactivity. They were divided into 15 groups of two and there were three students working on their own. All students studied applied geosciences in their 2nd semester and were therefore expected to have similar previous physics knowledge as students of mechanical engineering in their 3rd semester. All students could be seen as future users of the interactive instructions. Moreover, the students of applied geosciences performed the identical experiment on radioactivity under the same conditions to those of the physics laboratory for students of mechanical engineering in each winter term. Thus, it seems fair to assume that the study of experimental processes and problems presented here will provide useful hints for the design of the interactive instructions.

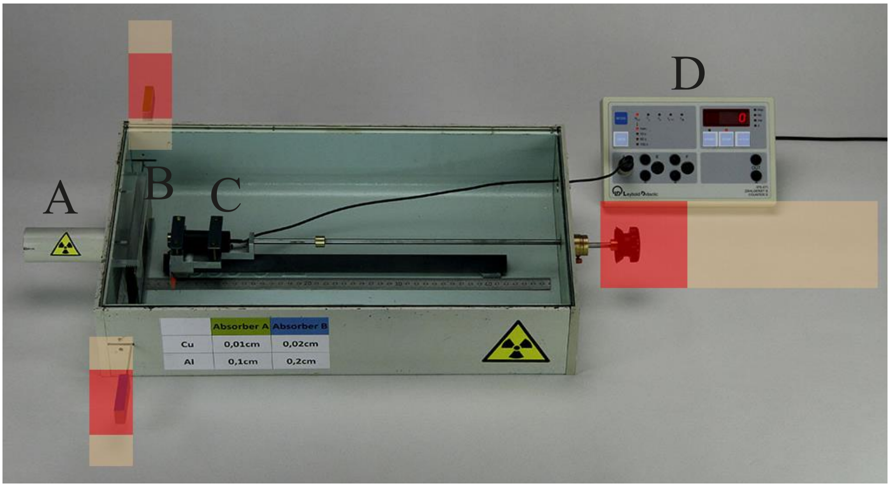

Fig. 3. Experimental set-up for the experiment on radioactivity: A: compound (Sr90), B: Geiger-Müller tube, C: absorption plates, D: counter. The red/orange and white shaded areas mark slide-zones and switches for the ISE.

3.1 The experiment on radioactivity

The experiment on radioactivity is part of a hands-on laboratory module called *"Messtechnisches Labor"* (laboratory for measurement instrumentation) for mechanical engineering students. The laboratory offers students the opportunity to familiarize themselves with important methods of measurement of physical data and to come to understand the functionality of the measurement devices themselves. It also helps students learn how the devices are to be handled, and how to analyze the results and sources of error.

In the experiment on radioactivity, the students examined the dependence of the intensity of radiation on distance from the radioactive source. From this data, the level of activity of the radioactive substance is derived by the students. In addition to this, radiation at a fixed distance is studied while two absorption materials are introduced as platelets of different thicknesses between the radioactive substance and the Geiger-Müller counter. This enables calculation of the absorption coefficients of these two materials and should help the students to understand the absorption of radiation in materials. The principal setup used by the students for the experiment is shown in Fig. 3. The figure presents a slightly simplified experimental setup which was prepared for an Interactive Screen Experiment, since the real experiment offers five absorption platelets instead of two.

The students are given a set of instructions for the experiment to read prior to the performance of the experiment. So far, these instructions have consisted of a printed 5-page manual which includes not only direct instructions for the experimental performance and the data analysis, but also basic physical information on radioactive radiation and its detection (see (Büsch et al., 2015)). The latter is of particular importance for the students, because it defines the scope of basic knowledge which students have to demonstrate in a discussion at the beginning of the corresponding date of the laboratory course. After a successful test of their basic knowledge, students have around 90 minutes time for practical performance of the experiment. This includes preparation and measurement as well as analysis of the acquired data. The general conditions described for the hands-on laboratory are independent of whether the experiment on radioactivity was performed by students of applied geoscience in their summer term or by students of mechanical engineering in their winter term.

Fig. 4. The Smartpen with its important features (source: www.staples.com).

3.2 Description of the Smartpen study

Smartpens, as shown in Fig. 4, exhibit broad functionality in recording data which qualifies them for collecting empirical data in learning processes. In particular, Smartpens can record important information that students produce while working in teams on an experiment and discussing and writing notes concerning their planning and observations (Dittmer, 2012): The Smartpen registers what students write and where they write it and simultaneously creates a coherent timeline. In parallel, it records the students' voices to get an impression of their communication and integrates these conversations into the timeline as well. Since the students work in teams of two, it is fair to assume that their communication is a good indicator of their thinking processes while making decisions as it has been done before in various video studies in practical physical laboratories (see for instance (von Aufschnaiter et al., 2007)).

In the present study, attention was paid not only to the discussions between team members, but also to questions to, and advice from, the tutor. To extract this information properly and efficiently, the tutor has a separate Smartpen complemented by a prepared log form to note supplementary information. The recording of this Smartpen is expected to reflect a problem-focussed summary of crucial points in the experimental performance, in our case ranging from the set-up of the experiment to the data analysis. The separate Smartpen for the tutor was introduced for the first time in this study, since it is important to pinpoint the students' problems during the execution of the experiment.

3.3 Results of the Smartpen study

As described above, the experimental process including the development of the experiment's journal, the discussions between the students, and the analysis of the measured data was recorded by the Smartpen used by the students while conducting the experiment. This approach was similar to an earlier study performed by Fraß et al. for another experiment (Fraß et al., 2014). Additionally, a tutor's Smartpen and a supporting log form were used in the present study to trace the students' questions in particular.

18 data sets were recorded in total (15 pairs of students in addition to 3 students working alone, see above). In 13 cases, there was reliable data from the students' and the tutor's Smartpen for the whole experiment. Only those data sets are used in the following analysis.

Results on the length of the experiment including data analysis: The total length of time required by the students for the experiment itself and data analysis, can be estimated reliably using the beginning and ending times of the recording. Fig. 5 shows that the students needed 100 minutes for the whole experiment on average with significant variation.

Results on interactions between students and tutor: The log form provided good insight into the number of interactions between the students and the tutor. Single conversations between tutor and students count as one interaction. In this context, a question including its answer was meant, as well as hints or advice from the tutor. All in all, there were 220 such interaction events, an average of 16 per group (fig. 6). There is again a clear variation in the numbers for different groups. However, no correlation between the number of interaction events and the time needed for the total experiment is visible.

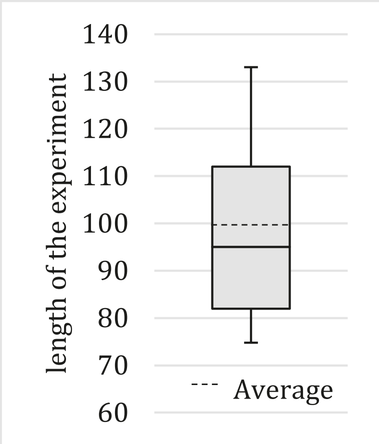

Fig. 5. The length of time required for the experimental performance including the analysis of the experimental data.

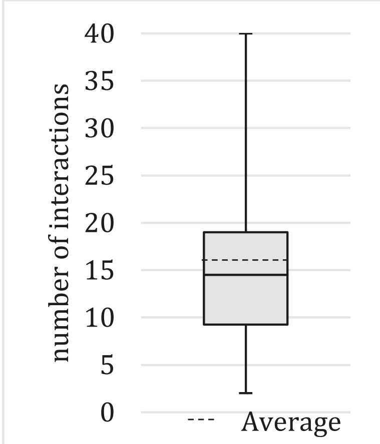

Fig. 6. Number of students-tutor interactions during the experimental performance including the analysis of the experimental data.

With regard to contents, three basic problem categories are recognizable as illustrated in Fig. 7. Several representative interactions from these categories will be discussed in the following sections:

a) Difficulties with the experimental set-up: The students had difficulties imagining the set-up beforehand and got to know the equipment while carrying out the experiment. The function of the Geiger-Müller counter was explained and the adjustment for distance and the absorption-plates was shown just before the experiment started. However, questions such as these were still asked: *"Is it set to 10 or 60 seconds?"* or *"How should we insert the individual plates?"* (translations by the authors).

b) Difficulties with calculations: The students had problems with mathematical calculations and considerations. It was hard for some of them to draw the line of best fit and to interpret its gradient, despite both being central themes in the preliminary discussion. The error propagation calculation was problematic as well, and was only done with the tutor's help. Typical questions from this section included: *"How do I do a linear regression?", "We are not sure how to plot this here?"* and *"Shall we calculate the error propagation?"* (translations by the authors).

c) Evaluation of the results: There were ambiguities as to whether the data acquisition was completed or the analysis was done correctly. The students were not sure if they had completed all tasks in their entirety or how to evaluate their results. Examples from this category include questions and statements such as: *"Is this value correct?", "Does this number make sense here?"* and *"We have calculated an unbelievable value here."* The tutor's advice as to which parts of data acquisition were still missing (despite the students confidently saying *"I believe we are done now"*) is part of this category as well (all translations by the authors).

All in all, the quantity and content of the manifold student-tutor interactions during the experiment's performance show that there is still much potential for better preparation for the experiment which can be supported by the supply of optimized instructions.

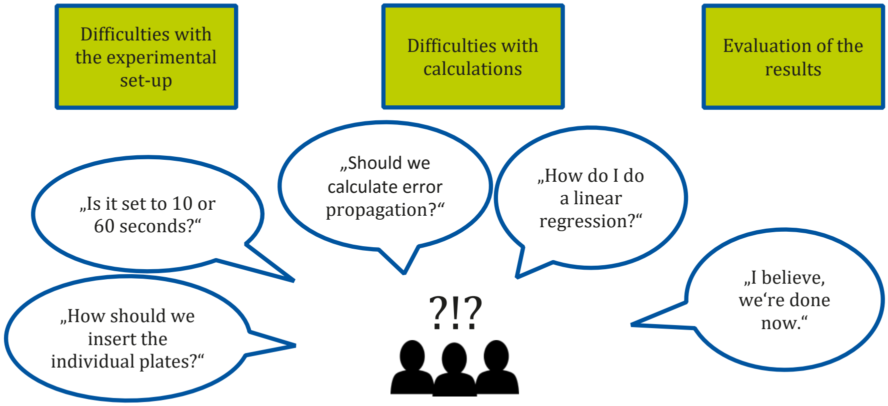

Fig. 7. Typically asked students' questions during the performance of an experiment on radioactivity including the analysis of the measured data (translations by the authors).

4 Outlook

This study has shown that data from a separate Smartpen for tutors, combined with the tutor’s log form, and students’ Smartpens reveals problems with the experiment in a very detailed way. From the problem categories derived above, conclusions can be drawn for the design of new interactive instructions as shown in Figure 8.

The data suggests a benefit in presenting the experimental setup in the new instructions in greater detail and in a more interactive way than in the traditional instructions. This demand is underscored by a study from Fricke et al., in which the students assess a hypermedia learning environment. This study was carried out during preparation for the experiments to provide a better understanding of the relationship between formulas and the experiment. It also aimed at a better realization of the experimental setup and greater clarity on the individual steps of the experimental process (Fricke et al., 2011). One way to address the deficit of knowledge in the setup is to include ISE. This permits trying out the first steps of the experiment and gives insight into the measurement tasks. An ISE has already been realized for the experiment on radioactivity under discussion as schematically shown in Fig. 3 and will be included in the upcoming new instructions.

The analysis of the tutor’s Smartpen data revealed student’s frequent ambiguities about whether data acquisition was completed and whether the analysis was done correctly as well as mathematical difficulties with data analysis. Some of these ambiguities and practical difficulties come from a lack of physical and mathematical background, as observed from the Smartpen data. To help students gain the necessary theoretical background as well as an understanding of the physics behind the formulas used in the analysis of the experimental data, we decided on short teaching videos as the appropriate medium. These short episodes with a maximum of 2 minutes duration are specially created for knowledge transfer and motivation. These videos could provide all necessary explanations of the theoretical background and practical application to data analysis. They could also provide further information for those who want to learn more about the topic. It is estimated that these videos will be watched to completion by almost all students due to their limited length (Handke, 2015).

Most of these videos will be spent on transferring important knowledge aspects. In addition, an introductory video will specifically focus on motivating the students in the particular area of the experiment, since increasing the interest of the students in the laboratory should enhance learning effectiveness. A similar approach has been realized before for motivational videos addressing medical students in a physics laboratory (Plückers et al., 2015).

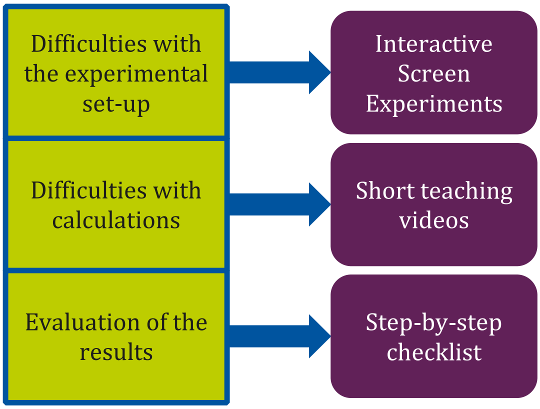

Fig. 8. Conclusions drawn for the conception of the new interactive instructions.

To address the student's uncertainties on the completeness of their measured and analyzed data, a step-by-step checklist will be included in the new instructions which will provide a better overview of the experimental processes. Since, in principal, the new instructions will enable an individual to regulate the speed and depth of information acquisition, this will also hold for the manual on experimental processes. However, these instructions will be structured in small steps which can be easily skipped by the user in order to manage one's own speed in conducting the experiment. This promises an efficient use of time for hands-on training (Theyssen, 1999). Aside from a clearer picture about the process of the experiment, the students should also be given more useful tools to check their results themselves and to have a self-contained reflection and evaluation about the overall experimental performance including data analysis steps.

All in all, the interactive instructions will serve as an opportunity for a non-linear use of the media of choice in a self-conducted manner and at one's individual speed.

The next step will now be to insert the essential information extracted from both the survey and the Smartpen study to the interactive instructions. Since Fig. 1 suggests an iterative development process for the new type of instructions, there must be adequate evaluation tools for studying the impact of the new instructions on students' experimental performance and its expected improvement. Smartpen studies are surely an appropriate instrument for this purpose. They can be combined with a new approach of object-focussed assessment in experimental processes which has been presented recently and opens even deeper insight into students' performance during the experiment itself and its development (Fraß et al., 2015).

For that reason, in the winter term of 2015/16, a video and Smartpen study was performed, which aims at an overview of students' actions while carrying out an experiment. The study will be expanded on by an object-based approach focusing on the important measurement parameters such as the position of the Geiger-Müller tube and the type and thickness of absorbing material in between the radioactive source and the detector. These data complemented by the settings and output of the Geiger-Müller counter will be monitored the entire time and be read directly during the experiment. Together, this data represents a complete data set with which one can reconstruct the experiment as it was carried out. This approach opens a new field of educational research on the development of process-oriented experimental skills (Fraß et al., 2015). However, it might also enable new insights into effective teaching procedures for experiments and hands-on skills. Technology-enhanced interactive instructions are one candidate for realizing such effective teaching procedures.

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Seeing How Fitting Process Works

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A common problem in teaching physics in secondary school arises from the gap in difficulty between physical concepts and the mathematical tools needed to model them quantitatively. Advanced statistical estimators are usually introduced only a couple of years after some common physical topics. Filling this gap with alternative methods appears to be appropriate in order to help students fully comprehend the issue they are facing. In this work, we use a smartphone camera and *GeoGebra* to propose a visual method to understand the physical mechanism behind a fitting process. The time constant of an RC circuit is estimated by fitting the discharge curve of a capacitor plotted on the screen of an oscilloscope.

1 Introduction

Fitting measured data from physics experiments plays a central role in engaging students in the models that they construct to describe, explain, predict, design and control physical phenomena. To develop insight into the formation of scientific knowledge by examining how models fit into theories and to show how scientific knowledge is validated, students must compare scientific models with empirical data (Hestenes, 1997). The discovery of a physical law behind observations requires the definition of a set of parameters, the number of which represents the assumed complexity of the model. In order to investigate and constrain the number and best estimates of these parameters, a fit against empirical data is necessary.

The concept of best fit of a data set, the degree to which changes in parameters in the proposed function change the best fit, and the uncertainties related to these parameters are all difficult to explain to high school students because of their lacking of advanced mathematical tools. Moreover, many attempts to show examples can be too abstract because of the use of software which does not explicitly show the fitting process. Linear or polynomial regression can be performed, for example, by MS Excel functions or by the Data tool of the Open Source Physics Project[1]. In each of these cases, with this kind of approach, the fitting process can be seen as a kind of black box.

For this reason, the development of new teaching techniques that can bridge the gap between available and required mathematical tools appears necessary. We propose an example of how this can easily be done with manual parameter optimization using a Dynamic Geometry Environment (DGE) such as *GeoGebra* (Mariotti, 2002).

This effective and active way of teaching how a fitting process works emerged in a course focused on physics lab didactics in the pre-service education of physics teachers. The proposal was designed during data analysis of an experiment on the RC circuit and is therefore intended to be tested with high school students struggling with electronics and electrical engineering.

1 http://www.opensourcephysics.org/webdocs/Tools.cfm?t=Datatool

Montalbano, V., & Sirigu, M. (2016). Seeing How Fitting Process Works. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 171–179). European Physical Society.

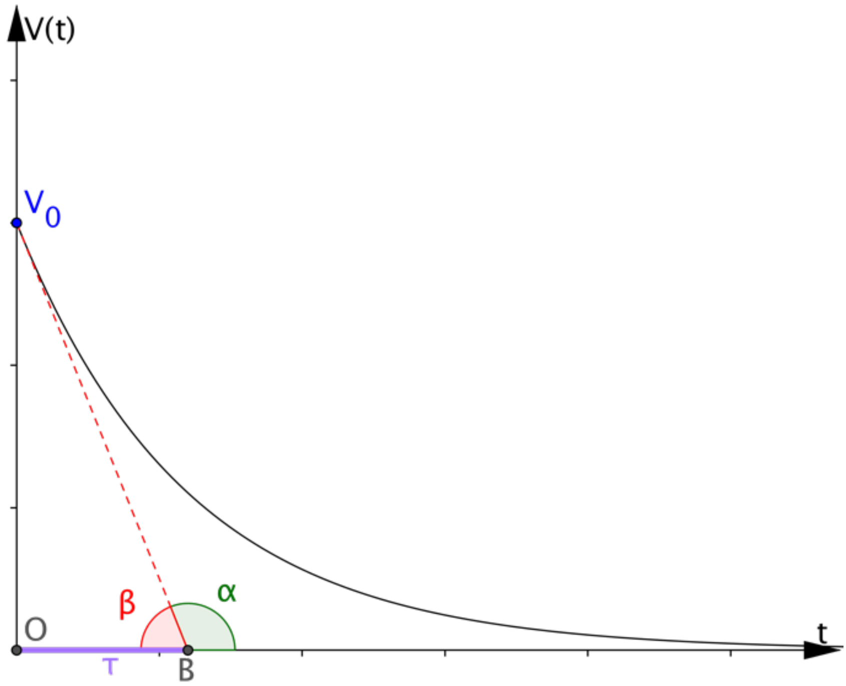

Fig. 1. The potential difference between the plate of a capacitor in an RC circuit during a discharge. In purple, the geometrical interpretation of the time constant of the RC circuit..

2 The discharge of a capacitor

Typical exercises when dealing with electric circuit analysis include the theoretically and experimental measurement of the electric potential curve of a capacitor in an RC circuit during discharge. When square wave voltage is applied to the circuit, assuming all other electric components are ohmic and the resistance of the cables is negligible, the flow of electric charges in the circuit is governed by Ohm's first law:

$$-\frac{\mathrm{d}Q}{\mathrm{d}t}R = \frac{Q}{C} \tag{1}$$

where dQ is the charge flowing in the circuit within the time dt, Q is the charge on each plate of the capacitor with capacitance C and R is the resistance of the resistor.

By assuming that at time t = 0 the circuit is closed and the capacitor fully charged, the differential equation (1) has the solution

$$Q(t) = Q_0 e^{-\frac{t}{\tau}} \tag{2}$$

where is the time constant of the circuit. By deriving and using again the Ohm's first law, this equation yields

$$V(t) = V_0 e^{-\frac{t}{\tau}} \tag{3}$$

which shows the exponential decay of the potential difference between the plates of the capacitor (see Figure 1).

Deriving the latter equation and recalling the initial condition that at time t, the potential derivative is graphically represented by the tangent of the angle between the t-axis and the curve *V(t)* in We can also show that τ can be graphically represented as the abscissa of the intersection point between the *t*-axis and the tangent to the discharge curve.

The time constant is a fundamental parameter that characterizes the circuit's response to a signal and can be experimentally measured by sampling the discharge curve of the capacitor.

3 Concept and implementation

The use of a DGE for obtaining and processing data is very useful in this context because it allows multiple goals to be achieved at the same time. With the DGE one can: speed up the sampling of the discharge curve; let the students expand their skills in analytic geometry; and show some unexpected applications, such as a simple method to understand how fitting process works. Moreover, this process can be a captivating way of conducting a physical experiment, since it makes use of multimedia tools, and can also strengthen the students' computer expertise.

3.1 *GeoGebra*

GeoGebra[2] is a powerful, easy to learn, and open-source software that provides a dynamic geometry environment. This tool is (or should be) extensively used in mathematics teaching (Hall and Chambleeb, 2013) to introduce geometrical construction and mathematical proofs and to provide visual and non-destructive tools for analytic geometry (Hohenwarter and Fuchs, 2005; Baccaglini-Frank and Mariotti, 2010; Leung, Baccaglini-Frank and Mariotti, 2013). It also implements data sheets, advanced statistical analysis tools (Prodromou, 2014) and 3D modelling (Oldknow and Tetlow, 2008). Within this work, *GeoGebra* has been used to bypass mathematical difficulties and to visualize fitting.

The discharge curve of a capacitor can be easily displayed on the screen of an oscilloscope connected in parallel. With a smartphone it is possible to take a picture of the screen and import it into *GeoGebra*. This procedure allows students to sample the curve with a high number of points in very little time: instead of visually taking measures directly on the screen and accounting for the scaling factor in the axes corresponding to time and potential, in a few clicks we can shift the picture in *GeoGebra* to match the grid of the Cartesian plane and define the units on the *x* and *y*-axis. By simply clicking on the curve, we can create points which will sample it very quickly. We can also analytically define an exponential curve to be superimposed on the picture. The parameters defining this exponential curve can be controlled to maximize correspondence with the experimental one. This procedure defines a manual and visual approach to the fitting process, and also allows an interdisciplinary approach to a physical problem by implementing analytical geometry tools and also reinforcing computer skills.

A fine-tuning of the parameters can also be performed by defining *sliders* as we will better explain in the following.

3.2 Materials and methods

As usual in pre-service education, low budget instruments and electrical components were used in order to reproduce the material commonly available in secondary schools and replicate the main experimental difficulties that can be faced during a lab lesson. In particular, the frequency of the square signal from the wave generator and the shape of the exponential discharge curve of the ceramic capacitor can be obtained by sampling the output of an analog oscilloscope (a GWInsteak GOS-622G with a 20MHz band width and a sensitivity of 1mV/div on both channels), connected to the circuit as shown in Figure 2. An accurate data reading requires at least a sample of 10 measurements of the differential potential as a function of time. Due to the limited screen size, the spread of the light trace, the scaling factors and the lack of a fine grid, these measurements can be difficult in some cases.

2 http://www.geogebra.org

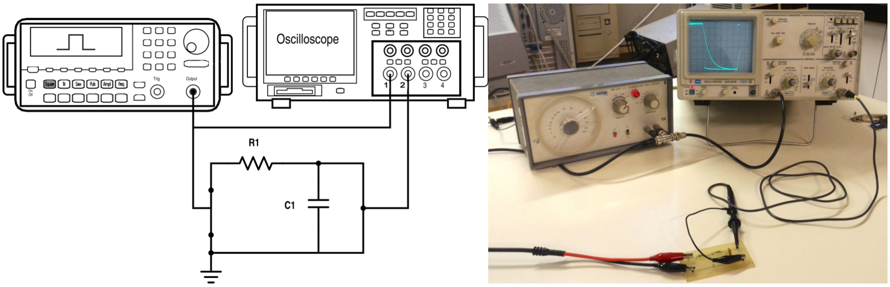

Fig. 2. Scheme of the RC circuit with a square wave generator and an oscilloscope in parallel to the capacitor (on the left) and the experimental setup (on the right).

3.3 Procedure

After setting up the circuit as shown in the previous section, we produced a square wave with a generator and plotted it on the screen of an oscilloscope. On the second channel we plotted the discharge curve of the capacitor. We changed the horizontal and vertical shifts and adjusted the scaling factors on the x and y-axes to show the discharge curve entirely and as broadly as possible, in order to minimize the uncertainty of the sampling.

We took a picture with a smartphone from a distance of about 3 meters, much greater than the screen size, to reduce the "fish-eye" effect that could affect the reliability of the measurements. The picture was imported into *GeoGebra*, then moved and resized to make the oscilloscope grid align with the Cartesian axes such that the discharge curve began at $t = 0$. The sampling of the discharge curve can then be done by simply clicking on several points of the curve. The coordinates of the points in the Cartesian plane correspond to the measure of time and potential difference respectively.

Finally, we superimposed an exponential function on the graph defined analytically as in (3) with a free parameter τ. V_0 is set to match the starting value of the potential difference just before the start of the discharge phase. The time constant is defined as an Action Object Tool of *GeoGebra*, a Slider tool, that can be adjusted manually over a certain range and with discrete steps. By changing its value, it is possible to visually understand the effects of different time constants on the time response of the circuit.

The τ of the circuit is measured by choosing the value which best matches the experimental curve, as shown in Figure 3. This curve can be compared to the best fit automatically generated by *GeoGebra* with the function *RegExp* which performs an exponential regression applied to the list of points that sample the discharge curve.

The uncertainty on τ can be evaluated by simply moving the slider and finding the upper and lower limits of the fit to the discharge curve.

Small discrepancies could be noticed between the values of the slider τ and the abscissa of the intersection point between the x-axis and the tangent to the discharge curve at $t = 0$. Exploring the cause of these discrepancies can be an excellent opportunity for deeper discussion on modelling, fitting and evaluation of uncertainties. Discrepancies could be ascribed to the residual distortion and misalignment of the picture to the grid of the Cartesian plane or to the choice of a model with only one parameter in the fit. In fact, the initial point of the curve was fixed without uncertainties. How this fact should be taken into account in the fitting process and how it influences the final results are questions for further tasks after data processing.

3.4 Data and Processing

An initial measurement of the frequency of the square wave can be directly obtained by the generator:

$$\nu_g = (19.00 \pm 0.25)\text{kHz} \tag{4}$$

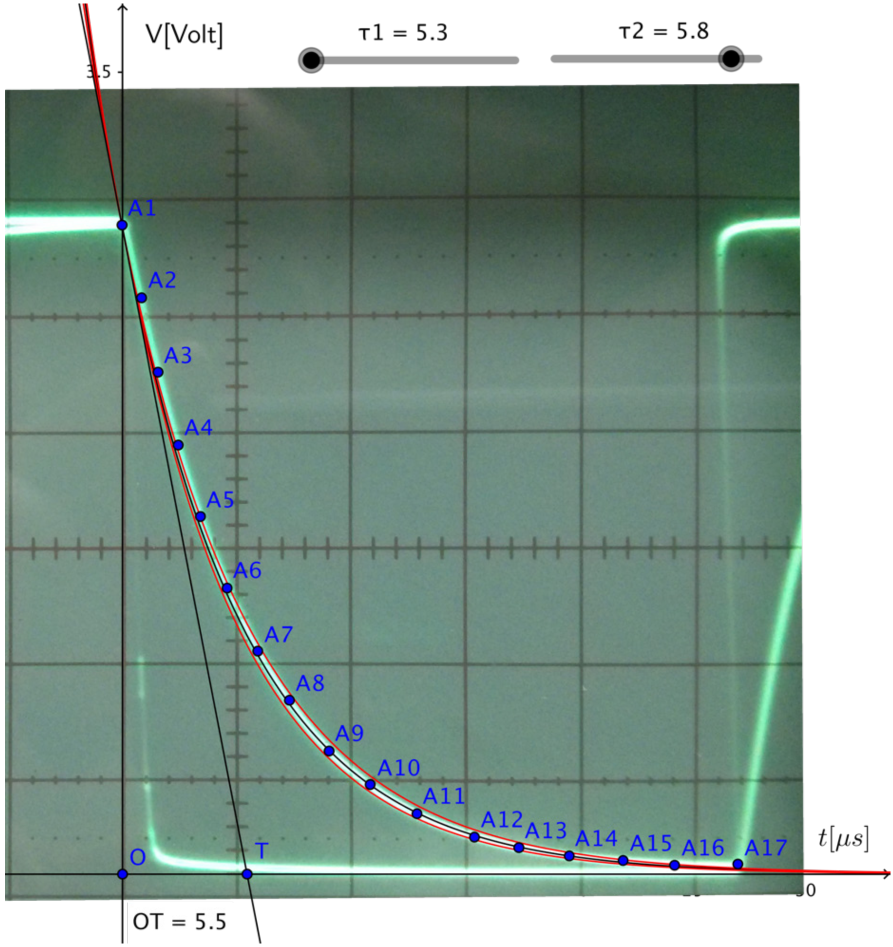

Fig. 3. Analysis of the discharge curve of a capacitor with *GeoGebra*. The picture of the discharge curve was imported into GeoGebra and aligned to the grid. The blue points represent the sampling of the curve. The black curve shows the exponential regression of the experimental points, while in red we see the curves corresponding to the upper and lower limit of the time constant of the circuit (the respective values are shown by the sliders on top of the image). The black line is the tangent to the best fit curve at $t = 0$ and the length of the segment OT represents the best value for τ in μs.

The semi-period of the oscillation is indeed shown by the screen of the oscilloscope:

$$T/2 = (26.0 \pm 0.5)\mu s \tag{5}$$

The uncertainty on the frequency is given by

$$\frac{\Delta \nu}{\nu} = \frac{\Delta T}{T} \quad \Rightarrow \quad \Delta \nu = \nu \cdot \frac{\Delta T}{T} = \frac{\Delta T}{T^2} \approx 0.4\text{kHz} \tag{6}$$

From the semi period we derive T=(52±1)μs, which leads to a second measure of the frequency:

$$\nu_0 = (19.2 \pm 0.4)\text{kHz} \tag{7}$$

which is consistent with the first estimate.

The measurement of the time constant of the circuit is obtained both manually (by moving the slider to match the analytic exponential curve to the experimental discharge curve) and automatically by the statistical exponential regression tool provided by *GeoGebra*. The tool returns the best values for the two parameters A and B of a function

$$f(x) = Ae^{Bx} \tag{8}$$

With our sampling points we get $A_* = 2.82$ V and $B_* = -0.19 \mu s^{-1}$, which corresponds to an estimated time constant $\tau = 1/B_* = 5.36$ µs.
To obtain an estimate of the uncertainty we define two exponential curves

$$g(x) = A_1\, e^{-\frac{x}{\tau_1}} \tag{9}$$

$$h(x) = A_2 e^{-\frac{x}{\tau_2}} \tag{10}$$

By moving the sliders τ_1 and τ_2 we find the two curves that envelop the experimental data. Thus, we obtain $\tau_1 = 5.1$ µs and $\tau_2 = 5.6$ µs and define

$$\Delta\tau = \frac{\tau_2 - \tau_1}{2} \tag{11}$$

Finally, we then obtain the best estimate for our time constant: $\tau = (\,5.4 \pm 0.3\,)$ µs.

4 Remarks and Conclusions

We provided an example of how the use of *GeoGebra* can be of help in sampling and analysing data in a physics experiment. We obtained a measure of the time constant of a RC circuit by importing a picture of the oscilloscope screen in *GeoGebra*, bypassing every difficulty related to the lack of mathematical tools and then comparing the results with the automatic fitting tools included in the software.

The method offers the opportunity to better explain the meaning of mathematical concepts such as the derivatives, the differential equations and the statistical estimators both from a geometric and a physical point of view.

This experiment can also be useful to stimulate curiosity and strategic and critical approach to a physical experiment both reinforcing manual and computer abilities. The use of *GeoGebra* can show how mathematics and geometry can be used in an unusual way to solve a physical problem.

The example of visualization of the fitting process described in the previous section reported the context in laboratory in which the method emerged and was initially performed. Since the ease and the range of situation in which it can be applied, a more effective use of *GeoGebra* in data analysis can be suggested. In the same context, a more sophisticated data fitting could involve the fit of all the parameters of the model.

Moreover, the analysis of electric circuits is not the more effective moment in which introduce the fitting process for at least two reasons. Students are introduced to electricity later in their study in physics, usually after mechanics and thermodynamics. But many experiments in these previous topics can be better understood if the fitting process is already introduced and well-established. Furthermore, the fit of an exponential curve is not the best way for introducing the visualization. Students are more accustomed to manipulating straight lines and interpreting proportional laws. Thus, the next step in implementing visual fitting is to design a learning path on a mechanical effect, such as deriving a spring constant using length vs. force on a spring, and test it in class.

The method was discussed in the group of teachers in the pre-service training and presented to a national congress of physics teachers, in both cases young teachers had immediately perceived the enormous potential for application in an actual teaching context at school.

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MULTIMEDIA IN TEACHING IN LEARNING QUANTUM PHYSICS

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-

Bobroff, J., Bouquet, F., & Jutant, C. (2016). New Ways to Reimagine Quantum Physics by Bridging the Gap Between Teaching and Outreach. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 181–187). European Physical Society.

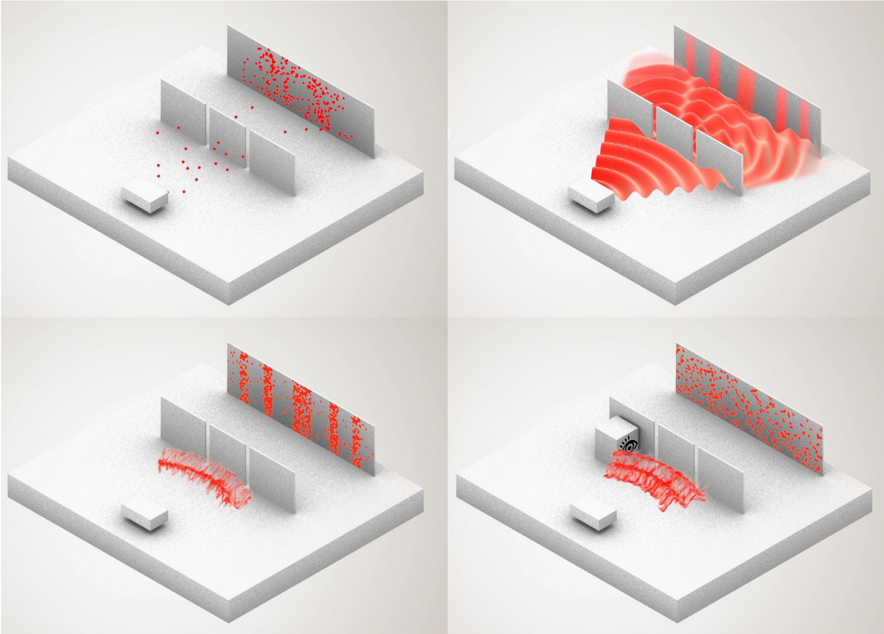

Fig. 1. Screenshots of the double slit experiment animation, displaying 1) particles 2) waves 3) quantum wave functions and 4) the same with an observer at one of the two slits (resulting in the destruction of the interference pattern) (full animation available at http://www.QuantumMadeSimple.com)

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-

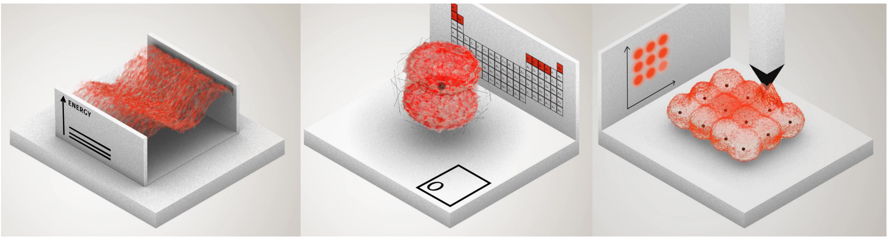

Fig. 2. Wave function representations in three different animations displaying 1) quantization in a box 2) atomic orbitals 3) scanning tunneling microscope (full animations available at http://www.QuantumMadeSimple.com).

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.commons.wikimedia.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 Danemark). 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

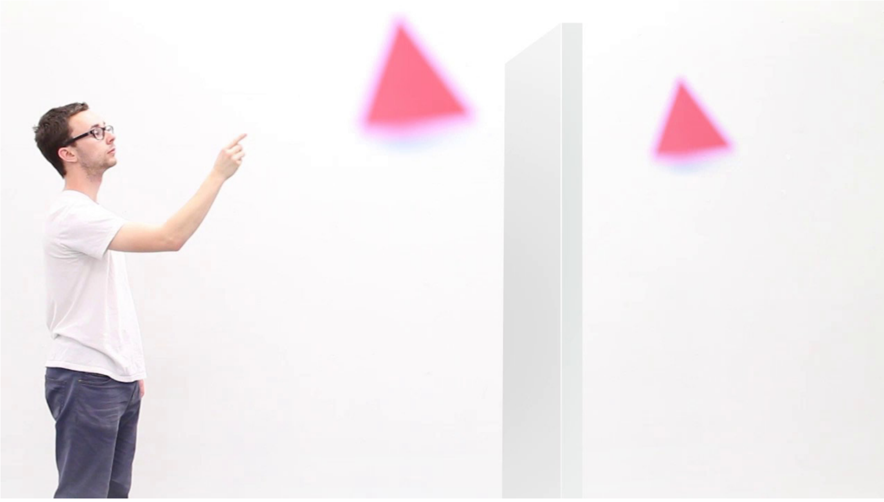

Fig. 3. Snapshot from the video "quantum thing" by the designer Paul Morin, which depicts a man manipulating large-size quantum wave functions, and in this image experimenting quantum tunneling.

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.

Acknowledgements

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A Learning Path on Quantum Physics Including Simulations, Low Cost Experiments, and Online Resources

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Over the last two years we developed a teaching-learning sequence (TLS) on quantum physics for high school, based on Feynman's "sum over paths" approach, and we tested it both in the training of perspective teachers and with secondary students. One of the distinguishing features of our TLS is the discussion of modern experiments (from the 1980's on) which are used to highlight the main conceptual aspects of quantum theory. In order to overcome the known difficulty in addressing experimental findings of modern physics in high school, we use a strategy which combines different elements: simulations of our own design, online resources including remote laboratories, and real experiments, performed with low cost and easily available materials and aided by open source software. In this paper we discuss some of the main innovative elements of our TLS, focusing on aspects concerning the use of multimedia resources; we also report some results from the tests we performed.

1 Introduction

The teaching of basic elements of quantum physics in high school is a notoriously difficult educational problem, which is nowadays becoming more urgent also in view of the objective to give all students the conceptual instruments needed to understand the process of technological and scientific innovation, and feel involved in it. Students' difficulties with quantum theory are typically both of mathematical and conceptual nature, and much research has been carried out on alternate depictions and mental models which can be developed by students who are first exposed to the subject (Johnston et al., 1998; Ayene et al., 2011).

Over the last two years we worked on developing a TLS in introductory quantum physics based on the "sum over paths" approach (Taylor et al., 1998; Cuppari et al., 1997; Fanaro et al., 2012). Such educational approach, based on Feynman's path integral formulation of nonrelativistic quantum mechanics, can help overcoming the difficulties of students in several ways:

On the mathematical level, the sum over paths approach allows to discuss quantum phenomena using a very simple formal language. At its heart, such possibility stems from the fact that, rather than finding solutions to the Schrödinger equation, Feynman's method constructs the Green function for the same equation, representing it as a sum of complex amplitudes computed over all possible paths. In educational practice, complex amplitudes associated to paths can be represented and added up as vectors or "little arrows".

On the conceptual level, the sum over paths methods also offers several advantages. First of all, Feynman's approach offers to students a very clear and unambiguous route to building an adequate mental model of one of its most profound mysteries, wave particle

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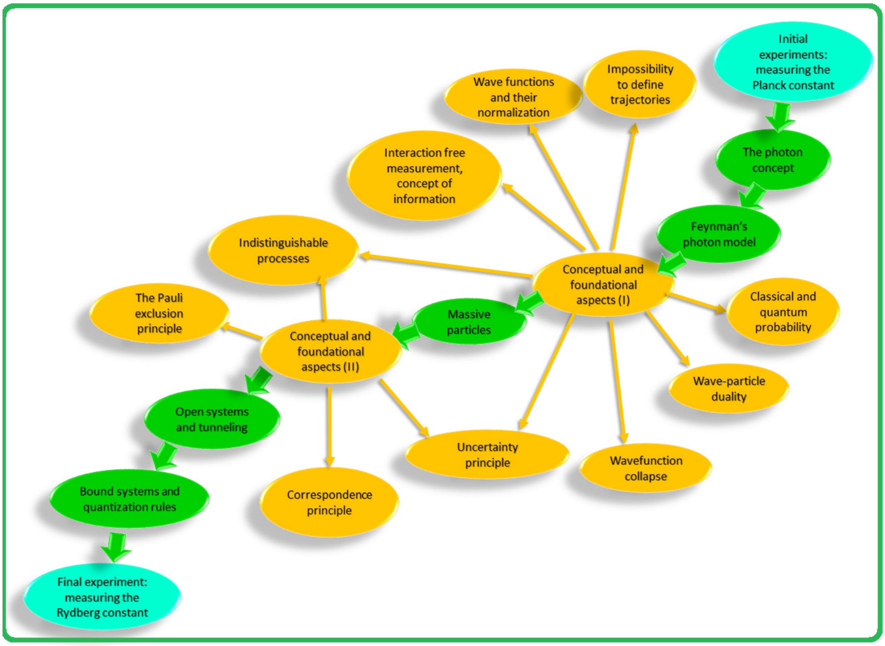

Fig. 1. Schematic representation of our TLS. In the central "spinal cord" of the schema are the main steps of the sequence, while orange ovals expand the content of the two steps labeled as discussion of "conceptual and foundational aspects". The only major difference between the tests with ST and in high school is that, at present time, the Pauli exclusion principle was not treated in the high school experimentation due to time constraints.

duality. The approach allows for the identification of a central difference between classical and quantum physics in how probabilities are computed for events that can happen in several alternative, indistinguishable ways. By doing so, it permits to construct a language by which several modern experiments in quantum optics can be discussed. Finally, the method makes the classical limit completely transparent, allowing an easy and convincing derivation of classical laws from the rules governing quantum systems.

Our TLS has been developed around the discussion of the conceptual themes of quantum physics applied to single photon interferometry experiments. Specifically, the interference across two slit of single sequential photons, the Grangier experiment (Grangier et al 1986) on photon indivisibility, the Zhou - Wang - Mandel (Zhou et al, 1991) result on the role of the information acquisition on quantum systems, the single photon Mach-Zehnder interferometer, and the Hong-Ou-Mandel experiment (Hong et al, 1987) regarding the consequences of photon indistinguishability. The introduction of modern experimental results is meant to present to students the subject of quantum physics as close as possible to its current understanding, and also, in many cases, to prevent the formation of hybrid quantum-classical mental models, which modern experiments can more efficiently refute. Of course, simply discussing the experiments in class is often not enough for students to grasp their significance: to overcome this difficulty we use a strategy combining simulations of our own design, and online resources such as videos, interactive representations of experiments, and virtual laboratories.

2 The teaching-learning sequence

Figure 1 shows a schematic representation of our TLS. Compared to the first implementation, discussed at GIREP-MPTL 2014 in Palermo (Malgieri et al., 2015), the sequence has

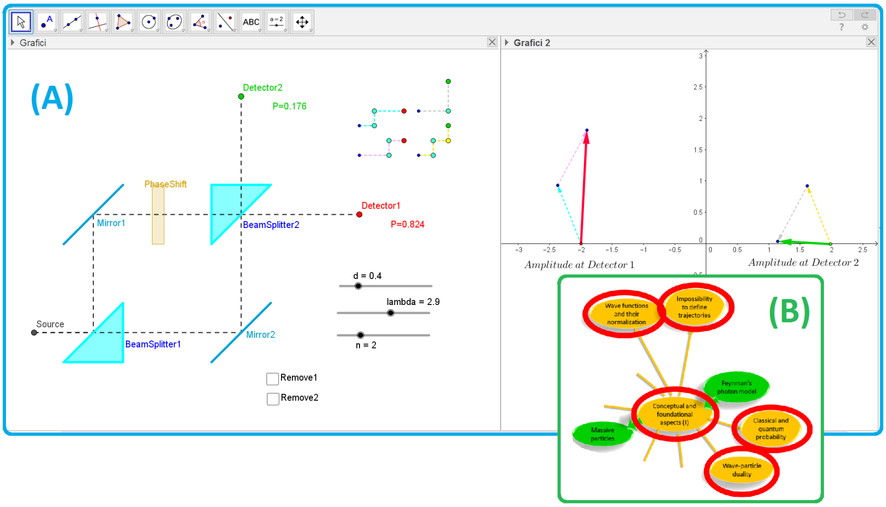

Fig. 2. (A) Simulation of the Mach-Zehnder interferometer, with removable arms and the possibility of varying the optical path length in one of the arms. (B) Placement of the simulation in the sequence highlighting the step and conceptual themes in which it is used (refer to fig.1 for step labels).

been enriched with a wider discussion of quantum model for massive quantum objects, and the experimental evidence related to it. We also expanded the introduction of typical stationary problems in one dimension from the point of view of Feynman paths (particle in an infinite square potential well and other bound systems, time-independent tunneling effect) and completely revised the experimental part, conducted with low cost materials. In 2015 the updated version of the sequence was tested both with a group of student teachers (ST) and in a senior class of a science-oriented high school (18-19 years old students).

Although our TLS is focused on conceptual understanding, we do not neglect the development of students' procedural abilities, such as the ability to perform exercises and solve problems. Thus, in the revised version of our sequence we increased the number of problems on the sum over paths approach to propose to students, and also specifically worked on connecting the language of Feynman's approach with the one used in textbook exercises (for example, comparing the different ways to solve the problem of finding the allowed energy levels of a particle confined in an infinite potential well).

2.1 Low cost experiments

As shown in fig. 1, the initial and final stages of our sequence consist of two experimental activities: in the initial one, students measure the Planck constant h using LEDs of different color. In the final one, students observe the hydrogen Balmer series and measure the Rydberg constant using a home-made low cost interferometer and the Tracker (v. 4.91, 2015) software (Onorato et al., 2015a). The experimental activities are not described here in detail as they are the subject of a parallel contribution also presented at MPTL 2015 (Onorato et al., 2015b).

2.2 Example simulations

Simulations realized with GeoGebra are used both in classroom lessons and for exercises and home activities. We realized 16 simulations in total, which we introduce at different points in the sequence. Some of these relate to phenomena that are traditionally addressed using the sum over paths approach. For example, the reflection and refraction of light, or the interference and diffraction of photons and massive particles. Other simulations model

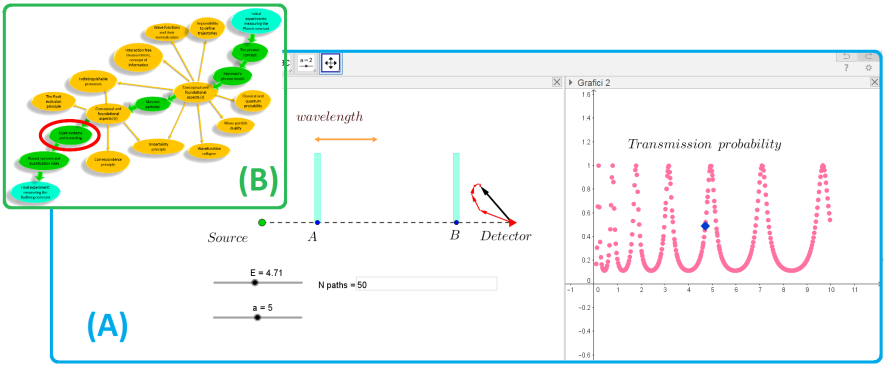

Fig. 3. (A) Simulation of an open system displaying resonant tunneling. (B) Placement of the simulation in the sequence highlighting the step and conceptual themes in which it is used (refer to fig.1 for step labels).

more advanced phenomena or experiments that are less commonly considered, especially from a sum-over-paths perspective. Here we concentrate on examples which are new or significantly updated with respect to previous implementations.

2.2.1 Mach-Zehnder interferometer

The Mach-Zehnder interferometer (fig. 2) is used in our sequence primarily as a conceptual tool for demonstrating the impossibility to assign an individual path to the photon (Malgieri et al., 2014, 2015), and effectively illustrates the differences between the classical and quantum ways of computing probability.

Assigning exercises to students requiring them to compute detection probabilities in a Mach-Zehnder interferometer setup with a variable optical path length is also useful in helping students to understand, at least in simple examples, the problem of normalization of amplitudes and probabilities.

In the revised version of our sequence we made more extensive use of this setup and its simulation and we also fine-tuned some details which had caused difficulties in student's understanding. For example, we changed the representation of beam splitters to resemble triangular prisms, since we found that this depiction made it easier for students to understand that the beam splitter produces a π phase shift to the photon amplitude for the reflected path on one of the inputs, but not on the other input.

2.2.2 Resonant tunneling from a double barrier system

In the final part of the sequence, we introduce a semi-open resonant system in which the detection probability depends very strongly on the energy of the incident photons, showing sharp resonance features. Such discussion is intended to provide a connection between the preceding analysis of tunneling from a sum-over-paths perspective, and the introduction of bound systems. The system, in the optical case, consists of a source emitting monochromatic photons towards a detector, with two successive beam splitters interposed along the path. In the case of a massive particle the role of beam splitters can be played by thin potential barriers of variable height, especially tuned in such a way that for any given energy the square modulus of the transmission coefficient is always $|t|^2 = 0.5$. By varying the energy E of the incoming quantum object, one observes that the detection amplitude goes from a very low minimum, to very sharp maxima. As usual, the maxima correspond to the case in which all amplitudes associated to two paths differing of a full back and forth reflection in the two barrier system are in phase. This system does not yet have a discrete set of energy levels; however, it strongly selects some values of the kinetic energy of the quantum object, for which the probability of detection is much higher.

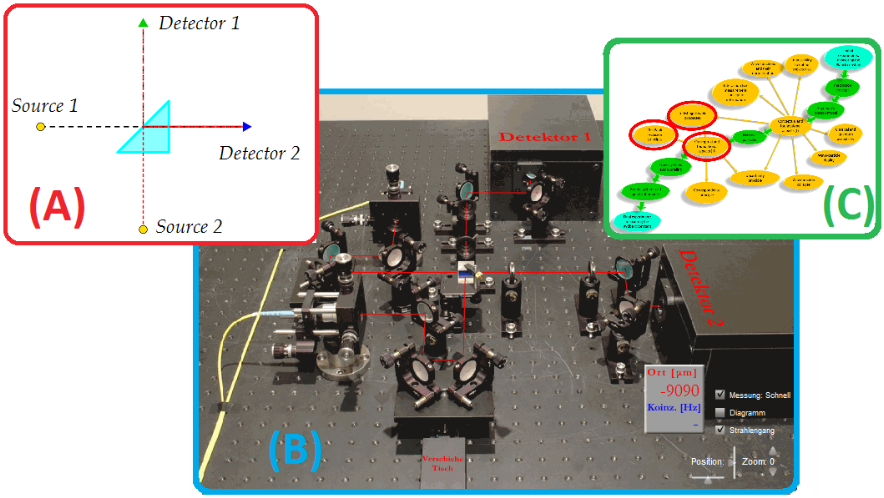

Fig. 4. (A) Schematic representation of the Hong-Ou-Mandel setup. (B) Online interactive representation of the experiment (Bronner et al., 2009; retrieved from QuantumLab, university of Erlangen-Nuremberg). (C) Placement of the simulation in the sequence highlighting the step and conceptual themes in which it is used (refer to fig.1 for the step labels).

In the simulation, shown in fig. 3, the left window contains the geometrical arrangement of the system; the adjustable parameters including the number of paths from source to detector to consider; the graphical representation of the sum of amplitudes at the detector; and an orange horizontal bar whose length is proportional to the wavelength of the particle. The right window contains the computed probability as a function of kinetic energy, which is graphed by a pink-colored point which moves and is tracked as E changes. Resonances, which constitute the main focus of example, are clearly visible.

2.3 Online resources

Our TLS also makes extensive use of resources available online to aid discussion of the experiments. The most important and most extensively used are, of course, remote laboratories and virtual experiments. These included the RCL-portal of the University of Munich, which we used for remotely controlled experiments on electron diffraction, as well as QuantumLab of the University of Erlangen-Nürnberg, the use of which we report on in the next subsection. We also used videos available online. Notably, we showed very similar videos of the two slit experiment with one photon at a time and one electron at a time (Roch et al., 2005; Tomonura et al; 1989), to reinforce the idea that all quantum objects obey similar laws and favour a unifying perspective on quantum theory.

2.3.1 The Hong-Ou-Mandel experiment

In our sequence we introduce the Pauli exclusion principle starting from a discussion of the generalized Hong-Ou-Mandel (HOM) effect. The original HOM experiment demonstrates destructive interference between indistinguishable processes which only differ by the exchange of identical photons. The setup (fig. 4 (A)) consists of two sources emitting perfectly indistinguishable photons toward the two inputs of a beam splitter, and two photon detectors positioned behind the two outputs of the beam splitter. The possible outcomes of this experiment are: a) two photons are measured at detector 1; b) two photons are measured at detector 2; and c) one photon is measured at each detector. This last outcome can be produced through two indistinguishable processes, which differ by the exchange of the two identical photons. Since the amplitudes of these two processes are out of phase by π, they cancel with one another. Consequently, the experimental outcome c) is suppressed, and photons are always found at the same detector.

In the educational presentation of this experiment the following steps are needed:

- Introduce the concept of interference between indistinguishable processes, or histories, from an initial to a final state, involving more than one quantum object. This can be done already starting from the Zhou-Wang-Mandel experiment, which we discuss in the initial part of the sequence.
- Introduce the rule for computing the amplitude for a process, as the product (in the sense of complex numbers) of the amplitudes corresponding to each individual particle involved in the process. Since in our TLS complex amplitudes are represented as vectors, the product of amplitude must be explained as the operation of multiplying the moduli of the two vectors, and adding up their phases.
- Compute the amplitudes of the two processes leading to experimental outcome (3), showing that they differ by a minus sign.

To have students understand an experiment of such complexity, it is necessary to provide them with more than a simple conceptual description. The online interactive experiments with single photons of QuantumLab, University of Erlangen-Nürnberg (Bronner et al. 2009, see fig. 4(B)) were of invaluable help in the design of our sequence, as they allowed us to offer to students a more direct experience of how the experimental setup is constructed, and what the data look like. Besides the Hong-Ou-Mandel experiment, we also used the QuantumLab interactive representation of the Grangier experiment of 1985 on photon indivisibility.

In our sequence, immediately after the HOM experiment we discuss the version performed in 2005 with indistinguishable electrons. In this case, as predicted by the rules of quantum physics, the experiment gives the opposite result: outcomes a) and b) discussed above are suppressed, and the electrons are always found at different detectors. The result can thus be generalized, allowing for the division of quantum objects into two separate categories:

- Objects which in a HOM experiment behave like photons: if indistinguishable, they are always both found at the same detector. Amplitudes for histories involving an exchange of two identical particles are computed with the usual rules; these particles are called *bosons.*
- Objects which in a HOM experiment behave like electrons: if indistinguishable, they are always found at different detectors. For such objects, amplitudes must be computed in the following way: taken one arbitrary history as a reference, all histories which differ from the reference one by an odd number of exchanges of identical particles, take a minus sign. These particles are called *fermions*.

By considering the abstract case in which two identical fermions, starting from different states A and B, could arrive both at the same state C, and using the previous considerations, we arrive to formulating the Pauli exclusion principle: identical fermions can never occupy the same quantum state.

3 Overview of results

In the first year of experimentation (2014), the TLS has been tested in training courses for high school teachers; while during the second year (2015) it was also tested directly with students of the final year of high school. Here, we summarize some of the most relevant results which we obtained from these tests.

Students generally produce satisfying and consistent mental models of wave particle duality, and use them with confidence for explaining phenomena. Answers to questions on this issue very often display a personal, non-borrowed language, and abound of examples and connections, demonstrating profound and integrated understanding. The appearance of hybrid conceptions reported in the literature is extremely limited. Results are good for high school students, and particularly impressive for ST. In this latter case, for example, the fraction of correct answers to multiple choice questions used to test understanding of wave-particle duality approached 100%. These multiple choice questions were taken both from the literature and from our own design. As an example, we report a typical explanation of wave particle duality produced by a student teacher:

"Acquiring information on a quantum system reduces the number of possible, indistinguishable paths. [Figure of a two slit setup with slits A and B] *If a detector in B reveals whether the photon has passed through B or not, then the possible paths are reduced only to the path from A or the path from B, thus there is no interference between paths. If there is no which way detector, paths through A and B are both possible, so they interfere. The amplitudes must be added up as vectors, and the probability is then the square modulus of the resulting amplitude. Hence, the interference pattern."*

A majority of students understand that the uncertainty principle has to be treated as an intrinsic limitation to the possibility of having two complementary variables (e.g. position and momentum) of a quantum system specified with arbitrary precision at the same time. They usually do not interpret the principle as a measurement error, or the result of a disturbance. However, in explanations of the uncertainty principle, students often appear to repeat an acquired notion, and have difficulty in making examples or connections. For example, in an open response item in which a high school student was required to criticize or agree with the "accuracy-disturbance tradeoff" interpretation of uncertainty (i.e. the "Heisenberg microscope" interpretation) reported in a widely used Italian textbook, he wrote:

"According to the textbook, it is only in the moment that man analyzes the particle, that uncertainty arises on its position and momentum. Actually this is not completely true, uncertainty in position or momentum of the particle always exists, independently from the fact that we study the motion of the particle or not."

While the general understanding of the meaning of the principle is certainly an encouraging element, the poor grounding of students' answers is an indication that our TLS may need further work on this issue.

High school students did not report difficulties in solving traditional textbook exercises due to being taught using a different approach from the one adopted in their text. Their results in graded school tests were equal or better to those obtained in previous subjects.

Finally, students appreciated the efforts to help them visualize and get a concrete feeling of quantum theory using simulations, online resources and real experiments. High school students appreciated in particular the experimental activities both in the real and remote laboratories. For example, in the context of the final interviews which we made to six high school students, one of them declared the following:

"In classical physics I can know the trajectory of ball which moves in the air with a certain velocity, but quantum objects can take more than one path simultaneously, freely. This fundamental freedom does not disturb me. (...) Experiment is very important, because in classical physics I can understand everything through mental images, for example the parabolic trajectory of balls thrown in the air... but how can I imagine the distribution of photons on the screen in a two slits experiments, if I don't see it?"

Student teachers were stimulated by the adoption of easy, open source, and well known software such as GeoGebra, and some of them produced their own simulations when solving the exercises assigned.

4 Conclusions

We have presented a teaching-learning sequence in quantum physics which incorporates the use of simulations, online resources and real experiments. We have summarized the most significant results from our tests with student teachers, and from our first test in high school. The main weakness of this study is that, in the classroom test, the teacher was also one of the authors of the proposal (M.M.). Although our data demonstrate the effectiveness of the proposal, the special context of the experimentation limits its generalizability. Thus, the addressing of transfer issues (dissemination of the proposal, formation of teachers to the task of implementing it in their own classrooms, and new tests of the results) must be considered a first priority in order to reach the stage of full validation (Méheut, 2004) of the teaching learning sequence. Currently, such work is under way, and we are at the stage of disseminating the proposal, primarily, although not exclusively, among those teachers who used our approach in their initial training.

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Visualising the Invisible – the Qubit as a Key to Quantum Physics

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We present an approach for teaching quantum physics at the high school level based on the simplest quantum system - the quantum bit, or 'qubit'. We show that many core concepts of quantum mechanics, including the superposition principle, the stochastic behavior and changes of state under measurements, and the Heisenberg uncertainty principle can be understood using simple mathematics. Moreover, they can also be illustrated with sleek visualizations. We discuss abstract features of qubits in general and consider possible physical realizations as well as various applications, e.g. in quantum cryptography. The approach can be expanded to multiple, where entanglement plays a key role. We develop illustrations and visualizations of entangled states and discuss fundamental principles as well as applications. The approach connects directly to modern research themes and topics that are associated with the Nobel prize for physics from 2012.

1 Introduction

Quantum physics is one of the central modern theories, and still a very active field of research (Wineland, D.J. (2013)). Despite this fact, curricula on quantum physics at the high school level are less developed compared to other areas of physics. Nevertheless, several attempts have been made to identify the key features of quantum physics and how to teach them (see e.g. L. D. Carr, L.D. & McKagan, S.B. (2009), DVD-ROM Quantendimensionen - Doppelspalt, Verschränkung, Quantencomputer (2010), Ford, K. W. (1966), Hobson, A. (2007), Hood, C. G. (1993), Kohnle, A., Bozhinova, I., Browne, D., Everitt, M., Fomins, A., Kok, P., Kulaitis, G., Prokopas, M., Raine, D. & Swinbank, E. (2014), Kohnle, A., Baily, C.R., Campbell, A., Korolkova N. & Paetkau, M. (2015), Manogue, C.A., Gire, E., McIntyre, D., & Tate, J. (2011), Mermin, N. D. (2003), Müller, R., Wiesner, H. (2002), Nielsen, M. (2003), Pospiech, G. (2008), Quantum Lab (2015), Schneider, M. B. (2010)).

Here we propose an approach to teaching quantum physics based on the simplest quantum system, the qubit (Dür, W. & Heusler, S. (2013), Dür, W. & Heusler, S. (2014), Dür, W. & Heusler, S. (2016)). The central idea of this approach is to use the quantum two-level system as a tool to introduce the key concepts of quantum physics. At the high-school level, we focus on sleek visualizations that allow one to illustrate all the basic concepts and ideas. At the undergraduate university level, we also provide a mathematical description where, unlike standard or historical approaches to quantum mechanics based on the wave function, simple mathematics suffices. In particular, only vectors and their manipulation are required.

The objective of this article is to promote the power of a qubit approach to quantum physics among high-school and undergraduate teachers, and to show that most of the central features of quantum mechanics can be explained and illustrated with a the simplest quantum system. Visualizations are the key element to this approach, where we show that quantum superposition, as well as stochastic behavior and state changes under mea-

Dür, W. & Heusler, S. (2016). Visualising the Invisible – the Qubit as a Key to Quantum Physics. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 197–204). European Physical Society.

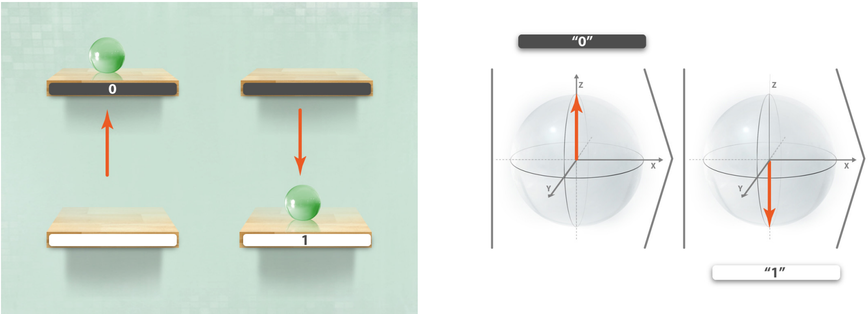

Fig. 1. Left: Illustration of a classical bit. Right: Illustration of the two basis states $|0\rangle$ and $|1\rangle$ on the Bloch sphere.

surement can be illustrated and explained. The qubit also provides a unifying framework that is novel to physics education, and allows one to make a number of different quantum scenarios accessible at an introductory level. This includes fundamental aspects, various physical realizations (Spins, photons, atoms), and modern applications directly connected to research (e.g. quantum cryptography and quantum communication (Gisin, N., Ribordy, G., Tittel, W. & Zbinden, H. (2002), Gisin, N. & Thew, R. (2007)), entanglement, teleportation, and quantum computation).

In the following, we will provide an overview on this approach. Further details can be found in (Dür, W. & Heusler, S. (2013)).

2 Qubit: States, Operations and Measurements

The quantum bit (qubit) is the simplest quantum-mechanical object that generalizes the classical bit (see figure 1, left).

2.1 States

A qubit represents a physical object with one characteristic property that can assume two possible values (see figure 1, right), while all other degrees of freedom are fixed or frozen. Basis states are denoted by $|0\rangle=(1,0)^T$, $|1\rangle=(0,1)^T$. Unlike the classical bit, superposition states are possible that can be illustrated with the help of the Bloch sphere (see figure 2, left). Any superposition state corresponds to a vector of unit length pointing in some direction in 3d space, $|\Psi\rangle=\cos(\vartheta/2)|0\rangle+\sin(\vartheta/2)e^{i\varphi}|1\rangle$, where the angles ϑ, φ are associated with spherical coordinates. In order to avoid mathematical difficulties with complex numbers, one may also use a Bloch circle by restricting to superposition states with real coefficients, $\varphi=0$. This allows for a simple, aesthetic visualization of many relevant properties and features.

2.2 Operations

States may be manipulated, corresponding to rotations of the Bloch vector. Mathematically, such an operation is described by the application of a unitary 2x2 matrix (Dür, W. & Heusler, S. (2013)).

2.3 Measurements

Perhaps the most striking feature of a single qubit is its behaviour under measurement. Unlike classical objects, quantum objects may be in a well-defined state, however some properties are nevertheless not pre-determined. That is, one cannot associate a precise value of a given property to the object prior to measurement. A measurement of such a property leads to a random outcome. Such an intrinsic randomness is a key feature of

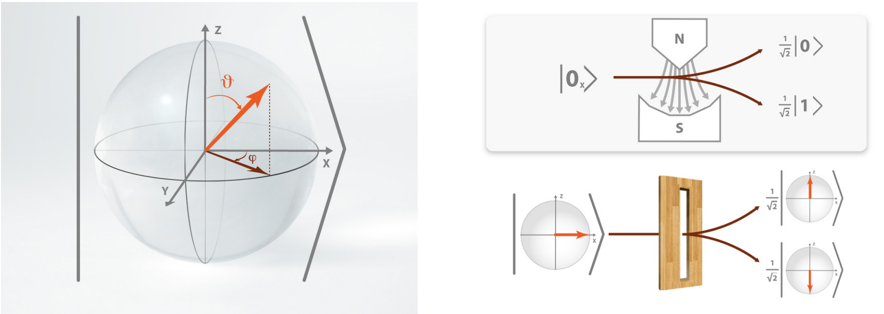

Fig. 2. Left: Arbitrary superposition state of qubit on Bloch sphere. Right: Measurement of Spin using Stern-Gerlach apparatus.

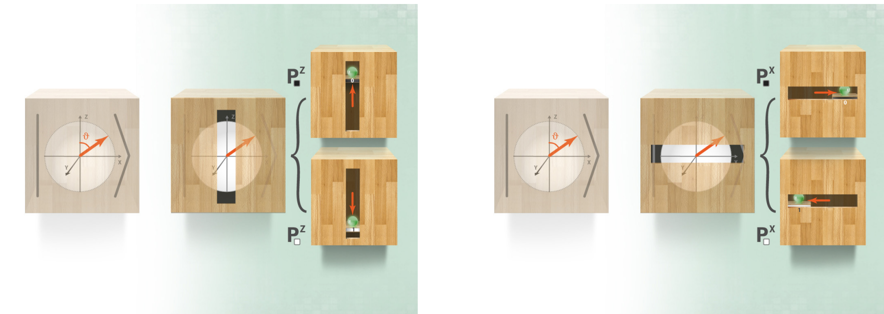

Fig. 3. Illustration of the z-measurement (Left) and x-measurement (Right) performed on a qubit in the state $|\Psi\rangle = \cos(\vartheta/2)|0\rangle + \sin(\vartheta/2)|1\rangle$. The slit is oriented in z-direction [x-direction]. The measurement process enforces a rotation of the vector in positive or negative slit direction. This leads to a random measurement result, and a change of the state.

quantum physics and distinguishes quantum physics from its classical counterpart. What is more, one also encounters a state change after measurement. That is to say, one cannot simply read out the value of a given property without changing the state of the system. For instance, a qubit in a superposition state $|0_x\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$ does not have a well-defined z-value. The measurement of the observable σ, i.e. the answer to the question of whether the system is in state $|0\rangle$ or $|1\rangle$, produces a random outcome. The state of the system is changed to $|0\rangle$ or $|1\rangle$ respectively (see figure 2, right). The probability of obtaining a certain measurement outcome is given by the square of the scalar product between the state vector and the vector describing the measurement result.

One can illustrate the measurement process with the help of a slit pointing in some direction in space. A z-measurement of the qubit corresponds to the slit pointing along the z-axis. For a superposition state $|0_x\rangle$ the state vector points in the positive x-direction and cannot pass through the slit. The schematic state vector must flip to either the positive or negative z-direction, leading to a random measurement outcome and a state change due to the measurement. While such a state has a well-defined x-property, its z-property is unspecified prior to the measurement. An x-measurement leads to a deterministic outcome, i.e. with probability $p = 1$ one finds the measurement outcome corresponding to $|0_x\rangle$ and the state remains unchanged as the vector simply passes through the corresponding slit that points in the x-direction. Measurements of z- and x performed on the state $|\Psi\rangle = \cos(\vartheta/2)|0\rangle + \sin(\vartheta/2)|1\rangle$ are shown in figure 3.

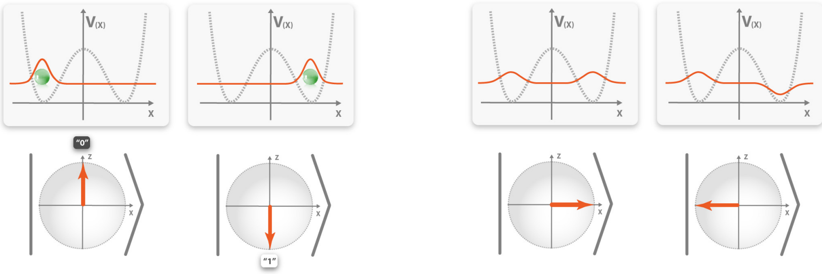

Fig. 4. Realization of a qubit using the spatial degrees of freedom of a single atom. Basis states correspond to the atom being in the left or right well (left), while superposition states are shown in (right) figure.

3 Physical Realizations

A qubit is an abstract object that allows one to illustrate many key features of quantum physics. However, when teaching quantum physics at the high-school or undergraduate level, it is of the utmost importance to connect these features to physical objects. In fact, a qubit may be realized in a number of different ways, and it is worthwhile discussing several of them.

3.1 Position of an atom

The position of an atom in the left (state $|0\rangle$) or right (state $|1\rangle$) well of a double well potential is an example of a qubit, where the position as a relevant degree of freedom can assume two possible values -see figure 4. Superposition states are depictured in figure 4, at right, and provide a nice illustration of the counter-intuitive feature of such quantum objects, as in this case the atom is on both sides of the barrier at the same time.

3.2 Spin

The spin, which can be thought of as the intrinsic angular momentum of a particle, is perhaps the standard example of a qubit. The Bloch sphere representation is directly associated with the orientation of the spin. The state of the spin can be manipulated by means of magnetic fields, and a measurement can be realized with help of a Stern-Gerlach apparatus (see figure 2, right). Notice that in such an experiment, the quantization of the spin was for the first time experimentally demonstrated.

3.3 Electronic states of atom

The internal (electronic) states of an atom or ion can also be viewed as a qubitif one considers only two of them (see figure 5, left). States are manipulated by appropriate laser pulses of just the right frequency (and hence energy) to couple the two electronic states. Measurements can be realized by making the ion emit photons only when it is in one of the two possible electronic states which can be made visible with the help of a CCD camera where the two measurement outcomes correspond to a bright or dark spot. Experiments with single atoms and ions are regularly performed in different laboratories, and an astonishing level of control has been achieved (Wineland, D.J. (2013)).

3.4 Photons

The polarization degree of freedom of a single photon can also be described as a qubit. Horizontally or vertically polarized photons correspond to basis states $|0\rangle$ and $|1\rangle$, while a superposition state $|0_x\rangle$ corresponds to 45° polarized light. While one can use known classical features of light beams to illustrate superposition states, it is crucial to note that

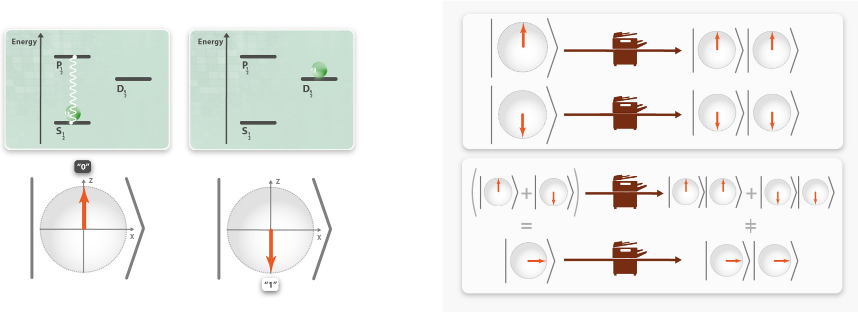

Fig. 5. Left: Realization of a qubit using the electronic states of an ion. Right: Illustration of the no-cloning theorem: a copy machine that can duplicate basis states fails to copy superposition states.

only when one deals with a single photon does one actually face a true quantum object that has all the features of a single qubit discussed above. Photon states can be manipulated by waveplates, i.e. with a birefringent material where horizontally and vertically polarized light travel at different speeds. Measurements can be performed with a polarizing beam splitter.

4 Applications

There exist a number of applications for even a single qubit. We discuss some of them in the following.

4.1 State tomography

First, one may determine the state of a system from multiple identical copies. Note that a single copy is not sufficient, as any measurement can only reveal one bit of information and the state is changed after the measurement. A combination of x, y and z-measurements performed on several identical copies, however, allows one to reconstruct the state, as the expectation values of these measurements correspond to the projections of the Bloch vector onto the corresponding axis.

4.2 No cloning theorem

The state of a single qubit cannot be cloned, see figure 5, right. One cannot simply determine the state of the qubit by measurements (see above), as would be possible for a classical system. Also, a unitary operation only allows one to copy basis states, but such a copy machine provides incorrect results for superposition states. This follows from the superposition principle of quantum mechanics, as a machine that successfully copies $|0\rangle \to |00\rangle$ and $|1\rangle \to |11\rangle$ acts on a superposition state as follows $|0_x\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \to \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$. This result is not equivalent to $|0_x\rangle|0_x\rangle$.

4.3 Quantum cryptography

The behavior of a single qubit under measurements together with the no-cloning theorem has far reaching consequences, and leads to one of the most promising applications of quantum technology. One can design a scheme that allows one to establish a secret key (and hence enable secure communication) between two communication partners (Gisin, N., Ribordy, G., Tittel, W. & Zbinden, H. (2002), Gisin, N. & Thew, R. (2007)). Security is guaranteed by the laws of nature, rather than some unproven assumption on the complexity of certain functions (as is the case in encryption technology used today). In particular, any attempt of an eavesdropper to reveal information of the quantum state by means of a measurement leads to a disturbance that can be detected, thereby guaranteeing security.

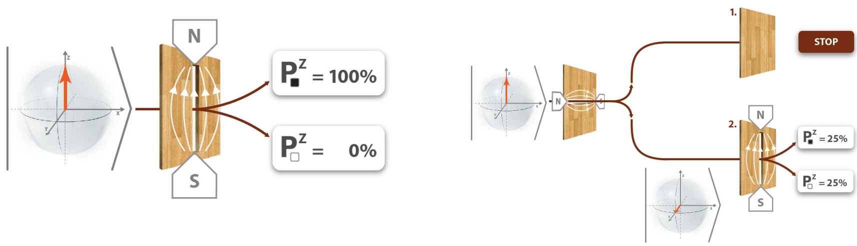

Fig. 6. A particle in state $|0\rangle$ will always be displaced upwards, and will hence never pass a filter where the upper arm is blocked (right). By adding a second filter oriented in the x-direction, the probability of passing through the overall arrangement can be increased.

4.4 Heisenberg's uncertainty principle

As outlined above, one may also qualitatively illustrate Heisenbergs uncertainty principle with a single qubit. If a state has a well-defined value with respect to a certain property, e.g. a specific z-value, then there exists a complementary property that is unspecified. If a vector points in a certain direction in space (e.g. the z-direction), its x-property is unspecified and an x-measurements yields a random outcome. A vector pointing in the z-direction cannot simultaneously point a specific way in the x-direction.

4.5 Filters

The state change of a qubit due to measurement leads to surprising effects. For example, consider a Stern-Gerlach apparatus where the upper arm is blocked, i.e. a filter where only state $|1\rangle$ can pass (see figure 6). While a qubit in state $|0\rangle$ will never pass the filter, an additional filter oriented in the x-direction, and placed ahead of the former leads to a 25% chance of the qubit passing through the two filters. That is, an additional obstacle increases the transmission probability.

5 Entanglement

When dealing with two or more systems, a new astonishing feature of quantum mechanics emerges. The possibility that quantum states can be in a superposition leads to the phenomenon of entanglement. For example, a valid state of two qubits is given by $|\Psi^-\rangle = \frac{1}{\sqrt{2}}(|0\rangle|1\rangle - |1\rangle|0\rangle)$. This state has the feature that any measurement performed on a single system yields a random outcome, but if the same measurement is performed on the other qubit the outcomes are always perfectly anti-correlated. For systems that are spatially separated, this anti-correlation can be viewed as a non-local feature of quantum mechanics. In fact, the violation of Bell inequalities (which has been confirmed experimentally with many different systems) tells us that quantum mechanics violates at either locality or realism (or both). That is, nature strongly contradicts our intuitive, classical view of the world. Entanglement can be illustrated with the help of a rotating coin, or with an (anti)-correlated double arrow (see figure 7). Entanglement is also a central resource in quantum technology, and allows e.g. transmission of quantum information via teleportation.

6 Summary and conclusions

We have demonstrated that many relevant features of quantum mechanics can be illustrated with the help of the simplest quantum system, the qubit. Even without complex mathematics, one can use aesthetic visualizations that we have developed to make these features accessible. In addition, we have shown how these quantum features can be used for practical applications such as in quantum cryptography. This provides an accessible

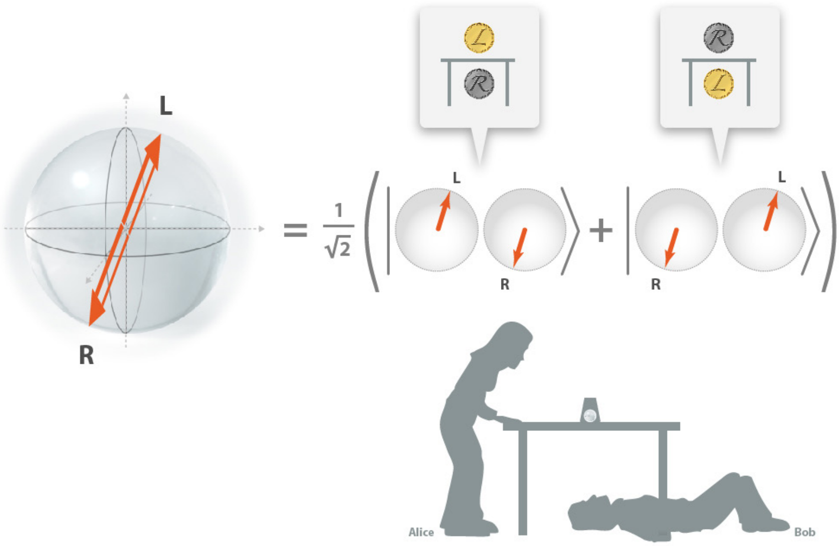

Fig. 7. Entangled states can be illustrated by double-vectors on a Bloch sphere. The antisymmetric state corresponds to a rotating coin, whose state is unspecified prior to the measurement (though correlated). A measurement in an arbitrary direction yields a random outcome, however the other particle is then in the orthogonal state.

approach to quantum physics in class. In addition, it also directly connects to modern research themes and applications in quantum information theory. Topics such as quantum cryptography, teleportation, quantum simulation or quantum computation can be naturally treated with this approach.

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Learning Quantum Information With Online Resources

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Quantum information is one of the most popular fields of quantum research today and has inspired fascinating technical applications such as quantum computers and quantum cryptography. The unique perspective of this discipline on information as a basic resource has the potential to successfully aid the teaching of quantum physics. In this article, we present an ongoing project to establish an online platform to learn about quantum information; the platform is targeted at physics teacher candidates. The project is freely available in German and partly translated into English at www.quanth-physik.de.

1 Introduction

Quantum physics not only represents the foundation of our current physical world view, but also the basis for current technological developments. Nevertheless, the topic is usually addressed only briefly in schools. It stands to reason that part of the aversion towards this topic stems from a persistent preconception that quantum physics is incomprehensible to most people. From a physics education research perspective, an important question is whether the traditional approach to the subject (which essentially follows the historical developments in chronological order) can still provide an adequate view of today's state of knowledge.

In our project, we want to implement a modern view on quantum physics, based on the principles of quantum information, which have been successfully applied in scientific research over the last two decades. The goal here is to use current topics like the quantum computers and quantum cryptography to raise interest and to transfer basic principles of quantum physics. Our target audience is primarily the physics teacher candidates at our university. The seminar we offer to them covers the basic principles of quantum mechanics in a quantum information context. The seminar also contains a set of four online courses which are presented in a just-in-time teaching format.

In this article, we review the basic motivation for using quantum information and the choice of topics for the courses. We provide a short description of the technical aspects of the project and then present results from an evaluation that has been conducted at the University of Hannover. We conclude by describing further initiatives of the project.

2 Why Quantum Information?

Quantum information is among the most active fields of quantum physics research today. Since its beginnings in the 1990s it has been established in many laboratories worldwide, covering topics from atomic physics to optics. One reason for the rapid success of the field is the fact that there are two major projects associated with quantum information: the quantum computer and quantum cryptography. The topic of quantum computing has been the recent focus of some media attention after a US American internet company (Google) announced that they had successfully implemented a quantum computer (Naughton,

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2015; Simonite, 2015). Quantum cryptography has been demonstrated at a technical level in different applications, yet the implementation in existing telecom networks is not feasible. Reports on different implemented testing networks are available at the following references: DARPA-Network, 2005, Secoqc-QKD-Network, 2010, QUCC-Network, 2015. For an overview of the technology, we refer to (Scarani et al., 2009). Part of the current research focuses on implementing quantum cryptography via satellite systems (cf. Vallone te al., 2015).

Apart from the technical aspects, quantum information has refined the way scientists look at quantum physics. The pragmatic approach of thinking about quantum systems as input-output relations seems to be a natural view for the topic and provides a mature level of conceptual and structural clarity.

One of the known obstacles in teaching quantum physics is that learners come with preconceptions based either on experience in the classical (i.e. Newtonian) world, or which originate from popular science sources. These preconceptions are known to be stable even when confronted in class (cf. Müller, Wodzinski, Hopf, 2004). By using the language of quantum information we hope to eliminate these preconceptions.

3 Basic principles

To present the fundamentals of quantum physics in a concise form and to provide learners with structured concepts, we developed the courses around certain basic principles of quantum physics. These principles are not intended to be an axiomatic basis of the theory, but rather to serve as guidelines to help learners interpret results. Our list of principles is based on previous work by Küblbeck and Müller (Küblbeck & Müller, 2002). Compare (Baily & Finkelstein, 2010) and references cited therein for a similar approach.

3.1 Statistical theory

Our first principle is that “Quantum physics is a statistical theory”. We take an operational viewpoint to quantum physics. Accordingly, we only consider preparations and measurements as fundamental entities and outcomes are presented as probability distributions over measurement values. We make a particular point not to talk about individual atoms or electron with individual properties, such as position or momentum, in order to avoid misconceptions. Our approach, following the statistical interpretation (also known as minimal interpretation), is to describe complete experiments predicting expectation values for equally prepared quantum systems.

3.2 Preparation uncertainty

Our second principle is that certain quantities cannot be simultaneously prepared on a quantum system with arbitrary precision. For example, the distributions of outcomes for a measurement of “position” and “momentum” of any preparation cannot both be arbitrarily sharply peaked for the same system. This presentation has the advantage that the terms (usually denoted Δx and Δp) that appear in the Heisenberg uncertainty relation can directly be interpreted as standard deviations of outcome distributions.

One should note here that different versions of uncertainty relations exist. The two most prominent are the preparation uncertainty relation and the measurement/disturbance uncertainty relation. The second form is also described in the form of Heisenberg’s microscope. In many textbooks for schools, these two versions are presented in an intertwined fashion, sometimes presenting the formula for the preparation uncertainty but discussing the measurement/disturbance relation. To avoid any confusion, we include the second version as the following basic principle.

3.3 No measurement without disturbance

The third principle states that is not possible to perform any measurement on a quantum system without disturbing the state of the system. Again the notions of measuring and disturbing have to be formulated in a statistical sense as distance measures on probability distributions, which makes the quantitative formulation of the principle cumbersome (cf. Busch, Lathi & Werner, 2014).

On the other hand, this version of the uncertainty principle has a direct application in quantum cryptography, where it is used to show that no eavesdropper can interfere with a given quantum system without causing a detectable disturbance.

3.4 Bell entanglement

Our last basic principle states that there exist correlations that cannot be explained by any classical local model of physics. States that exhibit these correlations are then called Bell entangled. The fact that the Bell inequality can be violated in nature (in agreement with the predictions of quantum physics) represents one of the most fundamental findings of recent physics and is a key ingredient to our modern understanding of the quantum world. It can, for instance, be seen as a strong indicator for the statistical interpretation of quantum physics and the existence of true randomness. The presentation of the theorem and its consequences are still quite complex and the derivation of Bell's inequality uses a significant mathematical abstraction.

To make the topic more accessible, we present the inequality using a narrative approach in which a story is told, involving two parties who perform the derivation in a game-like setting. Our goal here is to provide the learners with a surrounding in which consequences and implications of the theorem can be discussed.

4 Structure of course and lecture

The target audience of our courses consists of teacher students at the university. We have designed the online material to cover the content of one lecture worth three credit points (120 hours workload). The lecture is divided into four courses which use the same description framework, but are basically written in a self-contained fashion.

4.1 Course overview

4.1.1 Quantum physics of individual systems

We start by presenting the statistical approach to quantum physics and discuss the meaning of quantum uncertainty. The course includes an overview of all four basic principles from above, but focuses on the first two.

4.1.2 Quantum systems of composed systems

This course focuses exclusively on the derivation of the Bell-CHSH inequality and the application of the inequality in a narrative setting. This corresponds to our fourth basic principle.

4.1.3 Quantum cryptography

In this course we explain how the principle of "no-measurement without disturbance" can be applied in a cryptographic setting. The course covers an introduction to classical information theory and classical cryptography and a description of the BB84 cryptography protocol.

4.1.4 Quantum computing

Here, we describe the principles of quantum computing, and how the promise of quantum speedup is to be interpreted. We give a short introduction to the complexity classes P and NP and describe the basic ideas of quantum computing with the example of Deutsch's algorithm. The major quantum algorithms (Shor and Grover) are explained only briefly, as they would require deeper mathematical description.

4.2 Implementation

The course structure is implemented using the free MediaWiki software platform (MediaWiki, 2015). This platform is comparatively easy to implement and maintain, and most visitors are familiar with the design and the handling.

4.3 Just-in-time-teaching

The course follows the ideas of just-in-time-teaching (cf. Novak, Patterson, Gavrin & Christian, 1999). During the semester, the students are free to learn using the online material, with only a limited number of dates where all participants meet. In our case, we meet for one start-up session and then again four times over the run of one semester, each meeting devoted to answering questions about one of the courses. In accordance with the idea of just-in-time-teaching, all student questions are posted prior to the meeting in an online forum, which gives the lecturer the opportunity to cater the session to the students' needs.

The just-in-time method is a well known tool in teaching, and it is known that the method is effective, if only those questions that have been pre-submitted are answered. Otherwise the risk is high that students do not put sufficient effort into preparation for the course, hoping that the important points will be explained in the session anyway.

5 Evaluation

The course has been evaluated with students at the university in Braunschweig with different methods. In these test runs our goal was to enhance the quality of the material using a design-based-research approach. Here, we report on an initial evaluation that has been performed with parts of the course material at a different university and with a different instructor.

The courses "Quantum physics of individual systems" and "Quantum cryptography" were used as part of a general quantum information course at the University of Hannover in the winter term of 2014. The lecture was given by C. Morgan with an audience of physics master's students. The teaching format was a standard blackboard lecture, so the sessions using our material were the only ones with an inverted learning structure. To determine whether all students had really worked with the material, a short multiple choice survey was given at the beginning of each session. The results indicate that all students came prepared to the sessions.

Our question was how the presentation of the material influences the students' motivation. To address this, an adapted version of the short-scale for intrinsic motivation (Wilde, Bätz, Kovaleva, Urhahne, 2009) was used in a pre-post-design. The students were asked prior to the course to answer questions concerning their motivation in their general studies. Then after the course, the students were given the same questions only with respect to the course material. In total, eight students have taken part in both the pre- and post-test.

The results of the evaluation are shown in Fig. 1. The questions had originally been given in German but have been translated here. It can be seen that there were no significant differences between the pre-tests and post-tests in the subscales "interest", "perceived performance" and "perceived pressure", while the subscale "perceived freedom" showed that the students felt more free in their work with the online course. In the test, the students were asked to rate their approval to twelve statements on a five step scale from "total approval"' to "total disapproval". Three of these statements then form each subscale.

This result could indicate that using this online course is not harmful to students' interest, and could even be beneficial to their perceived freedom and hence to their overall learning motivation. The evaluation has only been performed with eight students, however, and all were in their first two years of master's studies, so the predictive power of the result seems fairly limited. One can also see that the students show a very positive image of their studies in general, almost all giving top marks to the question how interested they are in their general studies.

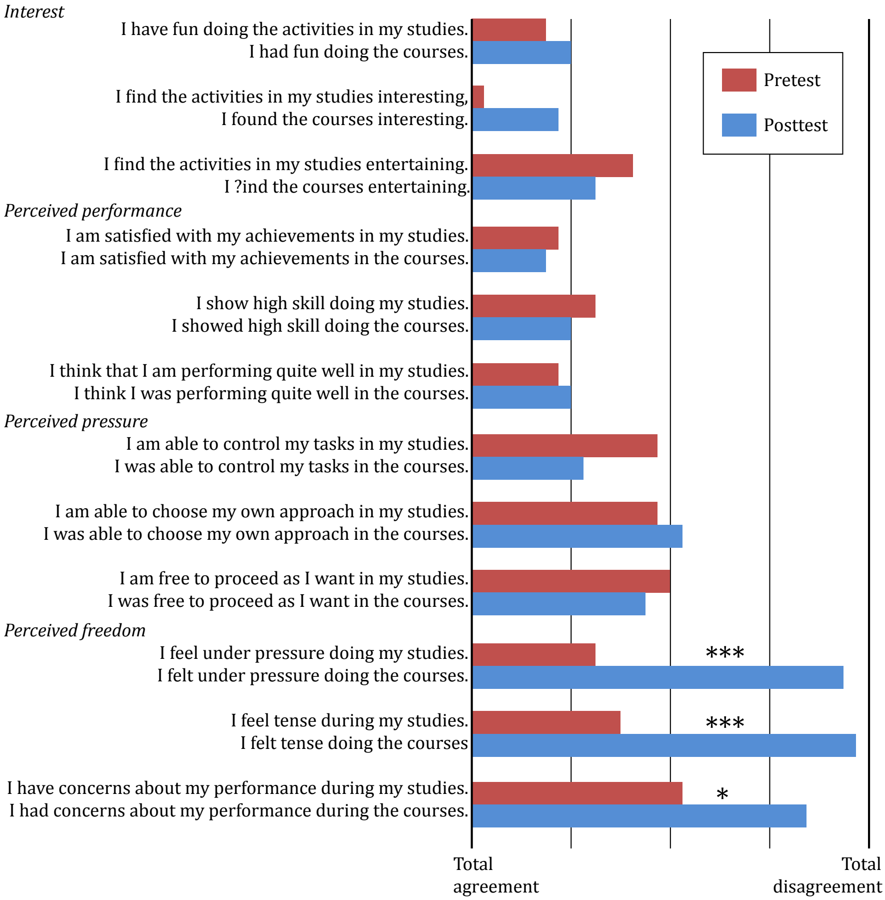

Fig. 1. Evaluation results from the survey in Hannover (n=8). The questions have been translated from German. Asterisks indicate the level of statistical significance.

6 Further developments

Currently, the quanth-physik.de website contains only written text and still-images, so the interactive options for learners is limited. In 2016, we want to make the system more interactive, by adding simulations and animations.

The animations will include simulations from the University of St. Andrews quantum visualization project (Kohnle, 2015). Preliminary evaluations with students at the university in Braunschweig showed promising results, so we expect an increase in learning efficiency.

For animations, we are currently producing an animated version of the narrative derivation of the Bell-CHSH inequality for the second course. Our approach here is to show an animated version of both the story and the graphical representation of the mathematical derivation in the same pictorial framework. To enhance learner's motivation and to make the topic more accessible, we decided to produce the animation in a comic style (see Fig. 2 for examples).

Another development is to make the topic of quantum information feasible as an introductory concept for schools. In a pilot project, a concept for using quantum cryptography in schools has been developed as part of a master's thesis at our university. The material was tested in a secondary school in Braunschweig (students were in 11th grade, two year

Fig. 2. Sample images from the development stage of the animation.

prior to graduation) initial results indicate that the topic could be feasible at schools. Our concept and findings are published (in German) in (Reisch & Franz, 2016).

7 Summary

In this article, we have given an overview on the contents of our quanth-physik.de website designed to help teach quantum information. We have described our motivation and why we see the quantum information approach as an interesting alternative to an introductory course on quantum physics. We have presented some evaluation results from the use of some of our courses at a different university and finally described the outlook for further development of the project.

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A Quantum Information Course With Python Simulations for Computer Science Students

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A quantum information course is presented for students of computer science at a university of applied sciences in Germany. Since the course is based on finite dimensional quantum mechanics, the only prerequisite is basic knowledge of linear algebra and complex numbers. The lecture is built on Python simulation exercises covering different toy models and quantum algorithms. The Python code is interactive, highly readable, easily modified, and has a strong visualization library. Writing and debugging computer programs can be a successful strategy for learning and approaching deep understanding; this can lead to independent research ideas. The central idea is that students get to know the core of the mathematical description of quantum physics in their own code and choose their own visualization which should help to prevent or overcome misconceptions that arise from flawed mental models.

1 Introduction

We are living in the century of emerging quantum technology. It is not yet clear how or if this technology will lead to quantum computers, but at the moment quantum cryptography and quantum information is already having an impact. It is believed that even a second quantum revolution is unfolding (see, e.g., http://qurope.eu/manifesto). Furthermore, quantum technology will play a major role in other important areas such as sensors, metrology, energy storage and energy conversion techniques (e.g., artificial photosynthesis).

In the author's opinion, it is of major importance to teach quantum mechanics, providing engineers and computer scientists with a basic understanding of quantum processes. Since prior physics knowledge cannot usually be assumed, we need a multidisciplinary curriculum rather than a traditional course in quantum physics. For this purpose, a good idea is to teach quantum informatics. While such a course comprises only simple systems, it still provides the most important concepts. Accompanying textbooks for undergraduate non-physics students are available (e.g., Yanowsky, McMahon 2008).

In addition to applications in quantum technology, highly interesting physics-related philosophical basic concepts like *Bell equations*, *realism* and *locality* are often fascinating to students. In the course that we are proposing, students will learn the mathematical description of quantum physics and write simulations of the models with Python. Different relationships can be visualized with graphs or networks. The students get to know the core of the mathematical description of quantum physics in their own code and choose their own visualization which should help to prevent or overcoming misconceptions. Writing, changing and debugging computer code may be a successful strategy to approach deep understanding. This way, the students get to the core of the problem without using simulations as a black box with a preset visualization.

Tornow, S. (2016). A Quantum Information Course With Python Simulations for Computer Science Students. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 213–217). European Physical Society.

```
Qubits
('q0', |0>)
('q1', |1>)
('output', 0.5*sqrt(2)*|0> + 0.5*sqrt(2)*|1>)
```

Fig. 1. A few lines of Python code to introduce the *kets* as well as the superposition of two states after a Hadamard transformation.

2 Quantum Information Course

2.1 Implementation and Learning Objective

The scheduled duration of the lectures is 180 min per week (for 14 weeks), divided into classes and tutorials with hands-on training. As part of the tutorials, different Python programs are provided to the students for private practice and to serve as a starting points for their homework assignments.

The subjects covered during the semester are: Short review of complex numbers, number theory, information theory and vector spaces, basic quantum concepts, qubits, quantum algorithms (e.g., Deutsch, Shor), cryptography, error correction, open quantum systems, decoherence and hardware.

After having successfully passed the course, students should be able to understand and follow current progress in the field and be able to participate in research projects.

2.2 Python Simulations

The course starts with the topics 'linear algebra' and 'complex numbers'. Here, the concepts of vector spaces, complex numbers and matrices are introduced with the help of Python. This also holds for the bracket notation which can be introduced with, e.g., the Python sympy physics quantum library.

In the following, a few examples taken from the different subjects will be described. As a first example, we consider the Hadamard Matrix ($U_H=\frac{1}{\sqrt{2}}(|0><0|+|0><1|+|1><0|-|1><1|)$). As described in Fig. 1 we start with the state |0>, and using a Hadamard transformation we obtain the superposition: $\frac{1}{\sqrt{2}}(|0>+|1>)$.

After the most important mathematical foundations, we start with the basic quantum mechanical concepts using networks. To explain the difference between classical probabilistic systems and quantum mechanical systems, we introduce probabilistic networks and quantum networks for a 4-state system which are visualized in Figs. 2 and 3, with the help of the library *networkx*.

If we start in state |0> or |3> (indicated by a red node) in the probabilistic classical system (fig. 2) the system evolves into states |1> and |2> after one time step, with probability ½ each. After the next time step the system returns into states |0> and |3>, with equal probability ½. The network is described with the adjacency matrix: A_{01}=A_{02}=A_{13}=A_{23}=½ (all other matrix elements are zero) and A_{ij}=A_{ji}. The transition probability is $P_{ij=}$ A_{ij}. With increasing time, the system switches between the right and left configuration.

We introduce quantum mechanical networks with complex weights. The network in fig. 3 is described by the unitary adjacency matrix with C_{01}=C_{02}=C_{13}=-C_{23}=$\frac{1}{\sqrt{2}}$ with $C_{ij} = C_{ji}^* = |i><j|$. Starting with state |0>, after one time step the state $\frac{1}{\sqrt{2}}(|1>+|2>)$ is reached. The probability of measuring |1> or |2> is ½ each. In the next time step the system is again in state |0>: The system is found to be in its initial state again and never reaches state |3> due to interference effects.

There are two important differences. In quantum mechanics, a given state can be a superposition like the state $\frac{1}{\sqrt{2}}(|1>+|2>)$. Once we measure, then the state gets determined to be either in |1> or |2>. In the classical case, the intermediate state is either in |1> or |2> with probability ½, independent of the measurement. The second difference is the interference. It is not possible to reach state |3>.

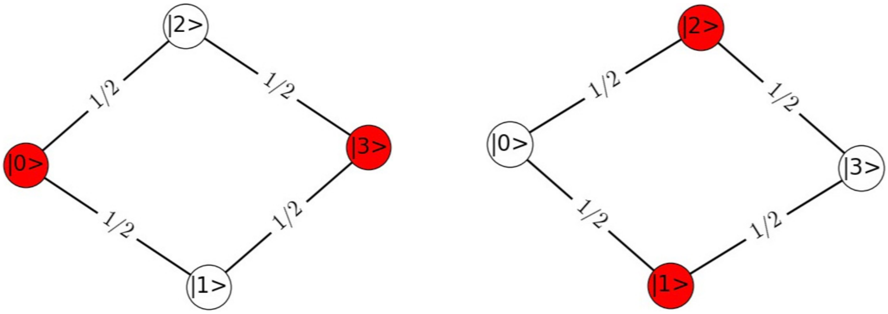

Fig. 2. Probabilistic network with probabilistic weights. Starting with state 0 or 3, the system switches between the left and right situation. Red nodes mark occupied states. The weighted edges are indicating the transition probabilities.

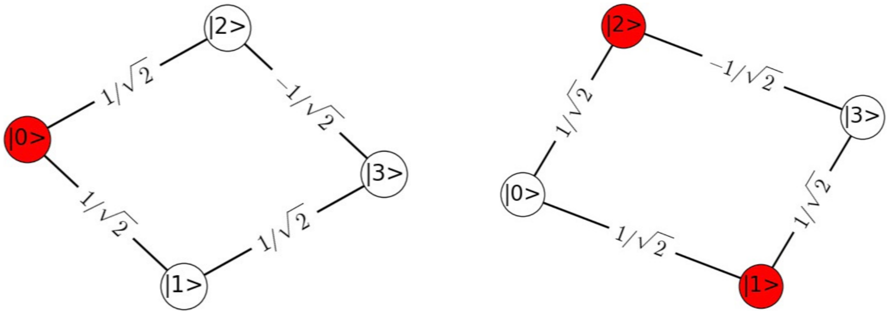

Fig. 3. Quantum network. The weighted edges give the transition amplitudes, the red nodes indicate occupied states. The state switches between left and right. The state |3> is never reached.

```
n=8
def f(i,j):
    f=E**(2.0*pi*I*i*j/n)/sqrt(n)
    return f
gt=Matrix(n, n, f)
```

Fig. 4. Python code for the Quantum Fourier transformation.

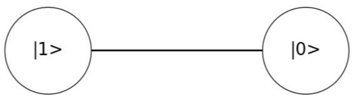

Fig. 5. Network model of a two state system.

The course continues by introducing gates and discussing quantum algorithms, e.g., the *Deutsch* as well as the *Shor* algorithm. One of the most important parts is the quantum Fourier transformation, an example of which is given in Fig 4. For each of the algorithms a Python code is written by the students. The next subjects are quantum cryptography, teleportation, error correction and hardware.

So far, only closed quantum systems have been discussed. In the remaining chapter the concept of an open quantum system will be described including error correction. The problems arising from decoherence and dissipation are discussed using a two level system (Fig. 5) that interacts with its environment as a starting example. Here, it is best to introduce the concept of density matrices, which is, e.g., for the state $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$, given by ½(|0><0|+|0><1|+|1><0|+|1><1|).The non-diagonal elements are the coherences indicating the potential for the system to show superposition and interference effects as in the network in Fig. 3. Conversely, the system described by a diagonal density matrix ½(|0><0|+|1><1|) is a statistical mixture describing a classical probabilistic system like in Fig. 2.

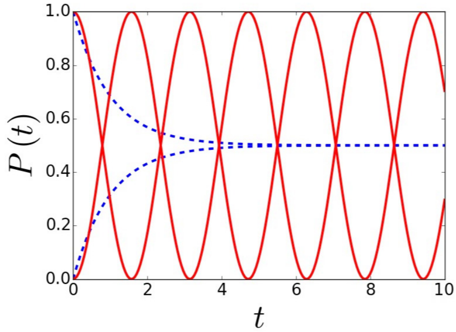

Fig. 6. Occupation probabilities of state |0> and of state |1> with and. The isolated two-state system (red, solid line) oscillates between 0 and 1 with mean occupation probability 0.5. The two state system coupled to an environment has lost its coherence and shows a relaxation to the ground state (blue dashed line), where states |0> and |1> have an occupation probability of 0.5 each. The time is in arbitrary units.

To visualize the behavior, we display the time dependent occupation probabilities of both systems. For this purpose, we solve the Schrödinger equation $i\hbar\frac{d}{dt}|\Psi\rangle = H|\Psi\rangle$ and calculate expectation values of an observable O with the density matrix $\rho(t) = |\Psi(t)\rangle\langle\Psi(t)|$ with <O>=*tr* (*ρ O*),*ρ*(*t*)=[*ρ*,*H*] where $|\Psi(t)\rangle$ is the state vector and O is the observable which we choose in our case to be O_0=|0><0| . O_1=|1><1|. The Hamiltonian H is chosen to be H=|0><1|+|1><0|. We assign the initial state $|\Psi(t = 0)\rangle$=|0>. As time elapses, the occupation probability oscillates between 0 and 1.

Since there is no dissipation included in the Hamiltonian, this oscillation will carry on indefinitely (Fig. 6, solid red line). The system cannot reach the ground state where the occupation probability of state |0> or |1> is equal to 1/2. These systems are ideal for building qubits and quantum computers. This is a stark difference from a real situation, where the quantum system interacts with its environment, introducing decoherence and dissipation to the system.

The usual description of such a case is the combination of, e.g., the two-state system with an environment (Nitzan 2006). In the density matrix formalism, the states of the environment are traced out, which results in losing the coherences and, depending on the coupling to environment, the density matrix can become diagonal.

If it is possible to neglect coherences, the system can be described in a classical probabilistic framework. We can easily simulate the transition to the ground state as shown in Fig. 6 (dashed line). The system is not described anymore by the Schrödinger equation but by Master- or rate equations for the occupation probabilities P_0 and P_1. The solution of equation $\frac{d}{dt}P_0 = k_0\,P_0 - k_1\,P_1$ is displayed in fig. 6 with P_0+P_1=1 (dashed line, with P_1(*t*=0)=0 and P_0(*t*=0)=1). The decay rates (k_0, k_1) are chosen to be ½.

If coherences are still present we see damped oscillations similar to the spin-boson model but this remains beyond the scope of the lecture (Tornow et al. 2008).

2.3 Evaluation

Achievement of the learning objectives as well as the lecturing itself is evaluated by formative anonymous tests during the semester. At the end of the semester, students attend an oral examination covering the course contents and present a term paper on a proposed or self-chosen project (possible subjects include quantum search algorithms, Schrodinger's cat, Bell game, adiabatic quantum computers, quantum simulation, etc.) which will be presented during the oral examination. After a series of lectures with about 15 attending students, we plan to provide a concept test covering the subjects of the lecture which will be evaluated and used to improve the following lectures.

3 Conclusion and Summary

With the knowledge of basic concepts – i.e., simple quantum systems, qubits, quantum cryptography, entanglement, basic algorithms and possible hardware - students should be able to assess and participate in computational scientists' developments of new technologies where quantum effects play a key role.

The core of this course is represented by the Python codes of selected model systems and by the simulation of the respective quantum algorithms. This leads to inquiry-based learning since not only visualization and animations but in particular the direct manipulation of the code fosters a deeper understanding of this challenging but intriguing subject.

Learning about quantum information, which may be easier than quantum mechanics itself, will lead to the possibility of being able to participate in the area of quantum technology.

As future work, we will investigate the students' conceptual understanding and its possible improvement by applying the Python programming exercises. The course was held in winter term 2015/2016. Recent first evaluation results showed that the course examination grades have indeed improved in subjects where Python exercises were provided.

Finally, we propose to use Python exercises also in classical physics courses for students with a strong programming background. We expect this to be especially suitable for those university or college environments, where experiments or physics laboratories are not available.

Acknowledgements

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An Interactive On-line Course in Contemporary Physics

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We describe the development of an interactive online course in contemporary physics. This course has already been offered as an on-site course for several years at Kansas State University for students who are not majoring in physics. In this project we have converted this on-site course into an interactive online course. The Online Contemporary Physics (PHYS 452) course includes written documents, hands-on activities and many interactive simulations. These simulations are heavily based on Visual Quantum Mechanics, which was developed to interactively teach concepts from quantum mechanics. These materials have also been supplemented by visualizations from PhET and YouTube videos. This online course has been offered twice with total of six students in previous semesters. Although we have a limited sample size, we have had some feedback from students on how to improve the course. We believe that the course is succeeding, and with additional input from students it will be more effective in teaching contemporary physics.

1 Introduction

A typical model for an on-line course, particularly for a massive open online course (MOOC), is a collection of lectures on video. Frequently, the lectures are divided into short segments which are examples of one-way transmission. Thus, they do not permit active involvement from the students, which physics education research has shown to improve teaching-learning effectiveness (Hake, 1998; Sayre et al, 2015).

Kansas State University has previously offered an on-site course on quantum physics for students who are not majoring in physics. This course, titled Contemporary Physics, includes hands-on activities, computer visualizations, and concepts using very little mathematics. Overall, the course was successful in terms of learning but attracted only about 20 students per semester.

The online course that is discussed in this paper is based on the Contemporary Physics (PHYS 452) course that we started almost 20 years ago and is based on Visual Quantum Mechanics (KSUPER, 2000). Here we will present a short overview of what we do in that course and then talk about how we deliver and assess it in an online mode.

2 Background

The main teaching/learning environment that we're trying to accomplish combines written documents, hands-on activities using inexpensive equipment, and finally computer visualizations. We put all these learning tools into a learning package that is based on the results of physics education research.

Figure 1 shows a typical on-site class in Contemporary Physics. As you can see by the kinds of monitors, this picture came from a class of about 15-20 years ago. This class was conducted on campus. At the time that the picture was taken the students were working with some of the visualizations. In this seating arrangement students can switch easily

Zollman, D., Ebini, R., & Üstün, U. (2016). An Interactive On-line Course in Contemporary Physics. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 219–226). European Physical Society.

Fig. 1. The Contemporary Physics course as it was taught in the early part of the 21st Century. Note that the students are actively engaged in the learning process. In this case some apparatus is on the table and they are reviewing to a visualization.

between computer simulations and hands on activities on the table. Thus, the class is highly interactive with students being regularly involved in both computer and hands-on activities.

The on-site course contains four major units. Solids & Light is the starting unit. Its primary goal is to study light sources and to help students see that we can obtain a great deal of information from analyzing light emitted by solids and gases and can build some rather good models just based on looking at this light and building models based on these observations. We start with the LED. We use atomic spectra and eventually reach a model for the quantization of energy as well as energy bands and gaps in solids.

In Waves and Matter we introduce wave functions mostly in a very qualitative way. The unit starts with particle interference and builds toward wave particle duality (including tunneling) and most of the standard issues in introductory quantum mechanics, from a qualitative point of view.

Seeing the Very Small is a unit on tunneling and the use of the scanning tunneling microscope. It has not been used very much because it is too complex for the intended audience.

Finally, Luminescence is a unit in which students build quantum models of various light emission sources and processes.

These units focus on how we know about the very small rather than just what the results are. We want our students to understand that physicists build models from evidence. Thereafter, those models can be tested in other contexts. In quantum mechanics the models work even though they seem somewhat strange.

Visual Quantum Mechanics (KSUPER, 2000), which is used comprehensively in the course, was developed to teach concepts of quantum mechanics interactively to secondary school students. The original materials rely heavily on worksheets in which students read introductions, conduct activities – both hands-on and simulations – and respond in writing to questions. The materials were evaluated extensively in a variety of secondary and university settings and have been shown to meet the goals of teaching quantum concepts to the non-scientist audience. (Escalada. 1997, 2001; Zollman, Rebello & Hogg, 2002)

3 From an on-site to an Online course

Contemporary Physics Online has been created to reach a large audience and to experiment with interactivity within an online environment. Our primary goal was to create a learning environment which would include a high level of interactivity while students learn about quantum mechanics and its applications. As with the on-site course, our audience consists of students who are not studying physics at the university level.

The core of both the on-site and online courses is Visual Quantum Mechanics. The core

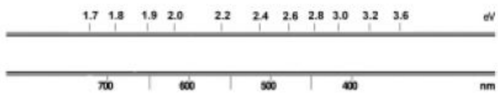
? What are the similarities among the light patterns observed for the various gases?

? What are the differences?

Now use the spectroscope to observe the light pattern emitted by the clear incandescent lamp. Connect the incandescent lamp to the circuit that you used in Activity 1 (See Figure 1-2) but without the use of the voltmeter. We will observe the light emitted by the incandescent lamp with the spectroscope when it is at maximum brightness.

? On the following scale, draw the pattern of emitted light observed with the spectroscope for the incandescent lamp. Use colored pencils or markers to indicate the position of observed colors. Add a written description to indicate any colors that are brighter or dimmer than others do.

Light Emitted by the Clear Incandescent Lamp



? In terms of the color, intensity, and patterns of light emitted, how is the incandescent lamp similar to the gas lamps?

? How are they different?

2-5

Fig. 2. Part of a page from the print version.

materials have been supplemented by visualizations from the PhET project (PER@CU, 2010) and YouTube videos.

For the online course we chose to concentrate on just the Solids & Light and Waves of Matter units. In terms of coverage, this decision represents a step down from the on-site course. The decrease in coverage reflects the fact that the students have limited interaction with teachers and peer students. We felt that because they are on their own, they will require more time to get things done. Our challenge was to move the materials from an on-site environment to one in which a student is sitting at his or her desk, perhaps a thousand kilometers away, and attempting to learn quantum mechanics. In this regard, we also

Further Exploration of Light Patterns

Getting Light from Gases 3

Now, switch to the Multiple Atoms tab at the top of the screen. Play the simulation. (It may start automatically.) This version is a little more realistic because many electrons are interacting with many atoms. As you can see a variety of different colors of photons will be emitted in this situation. To watch a spectrum build up, click the spectroscope option in the lower right of the screen. The default gas is hydrogen. Try at least one other gas. Record the similarities and difference between that gas and hydrogen.

Spectra of Gases

To see the spectra of a large number of gases click here. Scroll down to about one-third of the page where you will find the spectra of several gasses. These photos were recorded with a spectroscope very similar to the one that you made. The numbers at the top of each spectrum are the energies of the photons in electron volts.
For simulations of the spectra of a large number of gases using the best available data click here. This page contains some very old programming which is no longer considered safe. So, if you click on individual elements, your computer will probably refuse to run the program However, it is safe to look at the pictures. At the top of the screen is a so-called continuous spectrum. This spectrum contains all energies of photons in the visible range. As you saw with your own spectroscope, this pattern of light is observed for the incandescent lamp.
Skip the sun's spectrum for now; we will come back to it later. Look at the spectra for the various gases and answer the questions below. The pattern of light emitted by gas lamps is called a discrete spectrum. The general pattern is a set of bright lines of color in a dark background. The spectrum of the compact fluorescent lamp that you looked at with your spectroscope was similar to a discrete spectrum but somewhat more complex. It had some bright lines but also part of a continuous spectrum. We will discuss the details of why in a later activity.
To answer the questions below about the spectra that you have observed, click the question mark near the bottom of the page.

? What are the similarities among the light patterns observed for the various gases?
? What are the differences?

? How does the light emitted by the gas lamps compare to that emitted by an LED which you observed in a previous activity or an incandescent lamp which you observed with your spectroscope?

? Use your observations of the compact fluorescent spectrum and the spectra of gasses on the Web page to verify which gas is present in the fluorescent lamp. Describe how you reached your conclusion.

? Think about the energies of the photons being emitted by each type of light source, LED, incandescent lamp, fluorescent lamp and gas lamps. Write a short summary describing the differences in the energies emitted by the various sources.

Click here ? to answer the above questions.

Fig. 3. Part of a screen from the on-line version.

added a preliminary unit which includes introduction to fundamental forces, conservation laws, and photoelectric effect. This unit provides students with the background needed to begin the online course smoothly.

3.1 The Audience

In creating the course, we had several audiences in mind – in-service teachers, pre-service teachers, non-science students and secondary school students. In the US, most physics teachers are also teaching something else as their primary subject; this primary field can be almost any topic. Thus, physics teachers will have very little background in modern physics. For this reason, we would like to increase those in-service and pre-service teachers' knowledge of modern physics.

At our University and at many others, students who are studying most fields are required to complete at least two science courses – one biological and one physical science. This course could meet that requirement. An advantage over an ordinary on-site course is that they could schedule it as they wish.

Some secondary school students do enroll in university courses. For example, secondary school students have been involved in many MOOCs. While our course is not a MOOC, it could be attractive to some of these students. In the past we have had parents contact us to say: "My kid is bored with high school, and I saw your quantum mechanics stuff on the web. Would you give some of it to me so I can get him interested in learning something?" We always say yes. We hope that some secondary students will enroll in the course and enjoy learning quantum concepts while receiving university credit.

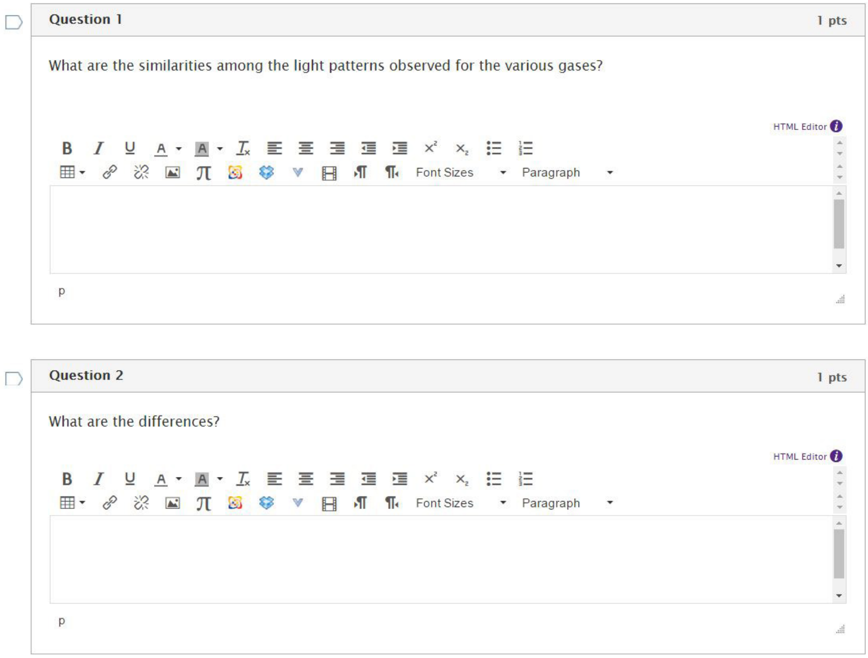


Fig. 4. Questions which the students respond to online.

3.2 The Course Components

While creating the online course we sought to include as many of the components of the on-site course as we could. Of course, we had no class meetings, but we wanted to have a high level of the student interaction with the learning materials – both hands-on and simulations. To assure interactivity, we included the questions and responses as on-line "quizzes" and made chat rooms available where students could discuss the materials. The most recent version of the course is available at https://k-state.instructure.com/courses/20350.

As an example of our conversion from paper worksheets to electronic ones, Figure 2 shows part of a page from the on-site Solids & Light unit. Note that the page has many blanks spaces for student responses.

Similar to the paper version, the online version has many questions for the students to answer (See Figure 3). We usually give the students a series of related questions and tell them to click. When they do so, the students get a screen as shown in Figure 4 where they can type their responses and add a picture or a graph.

For hands-on activities we have taken two approaches. For some activities we have lent the students some small items to experiment with and for the others we have had them make some items themselves. For example, in one activity students build their own spectrometer from an old CD and a cardboard tube.

A great deal of the experiment involves simulations. Figure 5 shows screen shots from two of the simulations that we use. One is from our Visual Quantum Mechanics; the other is from PhET. Both are part of the effort to teach about wave functions conceptually.

In both of these visualizations the students are required to manipulate variables and watch the results. We decided on asking the students to draw sketches rather than taking screen captures in the hope that the more active process of sketching would aid learning.

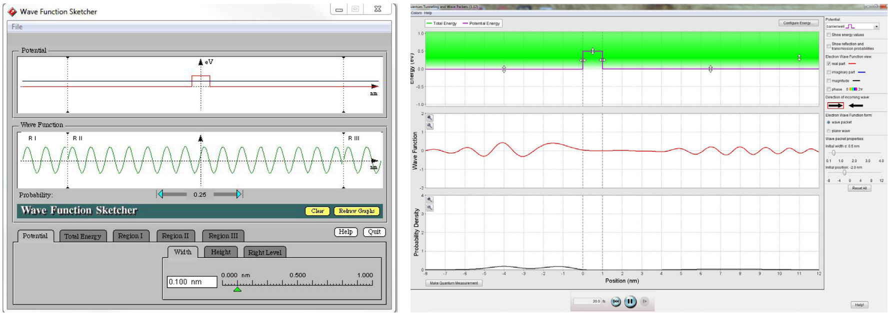


Fig. 5. Screen shots from interactive visualizations about wave function. Visual Quantum Mechanics is on the left; PhET is on the right.

		Course Grade				
	N	A	B	C	D	F
On-line	6	33%	17%	33%	0%	17%
On-site	~50	50%	25%	20%	<5%	<5%

Tab. 4. Comparison between student grades in the online and on-site courses when using the same test questions.

4 Assessment

We have attempted to assess both learning and attitudes during each implementation of the course. The course has been offered twice to a total of six students. This provides us with a limited sample size from which to draw conclusions.

4.1 Content Assessment

Learning was assessed by administering the same examination questions that were used in recent offerings of the on-site course. As Table 1 shows, the results have been mixed. The distributions of grades for the two versions of the course are not quite the same. However, the small number of students in the online version means that one student can make a big impact on the distribution. For example, the 17% failure corresponds to one student who did not complete the course.

4.2 Other Assessment

Feedback on the structure of the course and the interactivity has been collected from most of the students. The comments have varied and seem to be correlated to the level of success in learning the content. In general terms some of the issues that have been raised by the students are listed below. Our attempts to address some of these concerns are listed under the concerns.

- An online course should be easier than an on-site course
- Too much reading
- Lack of "interaction" with instructor
  - Add some home-made videos to introduce topics
- Better guidance through the instruction
  - Add interactive concept maps of each topic
- Need more hands-on activities
  - Take home labs
  - Need good ideas
- Not much peer interaction

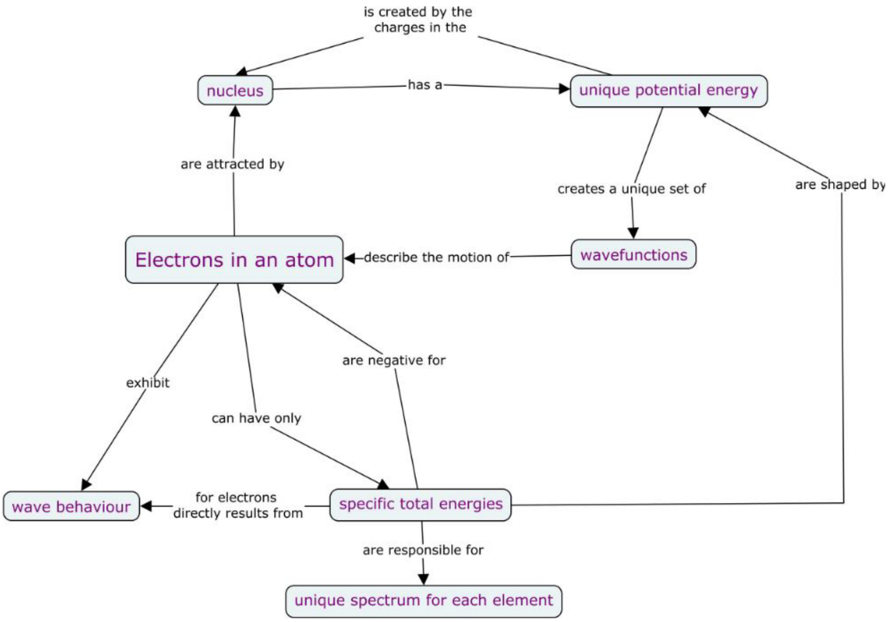


Fig. 6. An example of a concept map we created for one of the modules in the course.

As an example of our modifications to address these concerns, we will introduce interactive concept maps to help students see the structure of the content better. We have already created the concept maps related to each module and now we are in the process of integrating them into the course. We will use these concept maps at the beginning of each module as an advance organizer. Figure 6 illustrates one of the concept maps we created for one of the modules within the course.

5 Conclusions

While we have some work to do, we feel that some parts of the course and its development have succeeded. The following items and actions seem to have gone well:

- Conversion from paper tutorials to web pages
  - Relatively easy but took time
- Integrating reading, simulations, videos from others
- Student engagement with all components
- Student experiments at home
  - Only a few, but successful
  - Examples
    - Spectroscope from an old DVD
    - Properties of LEDs

We anticipate that with further modification and additional input from students, we will be able to provide a good learning experience.

Acknowledgements

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TECHNOLOGY ENHANCED LEARNING AND TEACHER TRAINING

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

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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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 229–236). 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

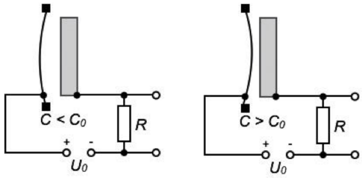

Fig. 1. An example of two images showing the minimum and maximum state of a capacitor microphone. If the tet.box that contains it is set to slideshow, the images get placed on top of one another, with only one showing at a time. Thus, the student can operate the device virtually, bending the diaphragm,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

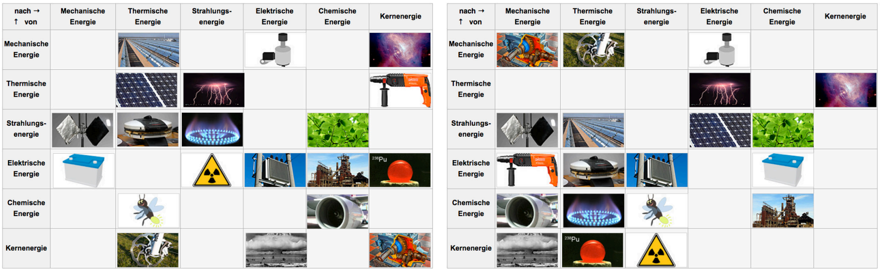

Fig. 2. A puzzle about the different means of energy transformation in daily life. The student can document their learning progress by moving the tiles from their starting places (left figure) to their correct places (right figure).

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.boxes, 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.

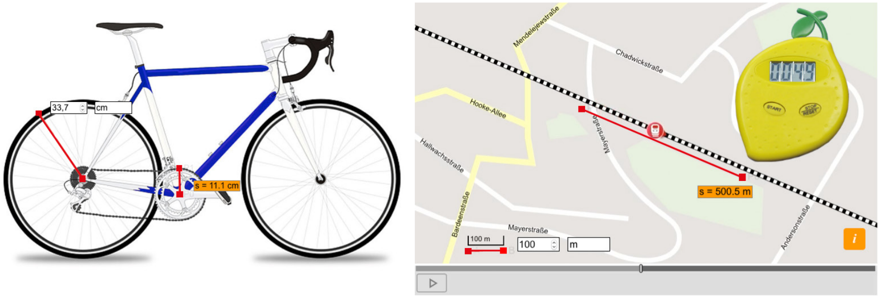

Fig. 3. Universal tet.tools can add extra learning activities to existing ISEs, images and videos. Here, the length tool is used to compare the radius of a bike's gear rim to its wheel radius. The same tool is used to measure the travel distance of a train, together with the stopwatch tool to measure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

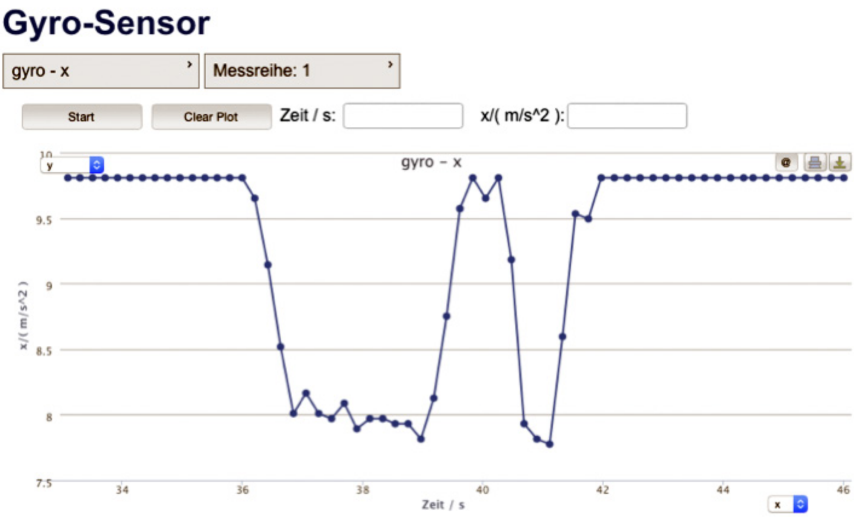

Fig. 4. HTML5 can read the gyro/acceleration sensor built into most smartphones. The tet.folio tool shows a measurement of the Earth's gravitational acceleration of about 9.8 m/s^2. Slight tilting results in changes of the measured value over time.

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-

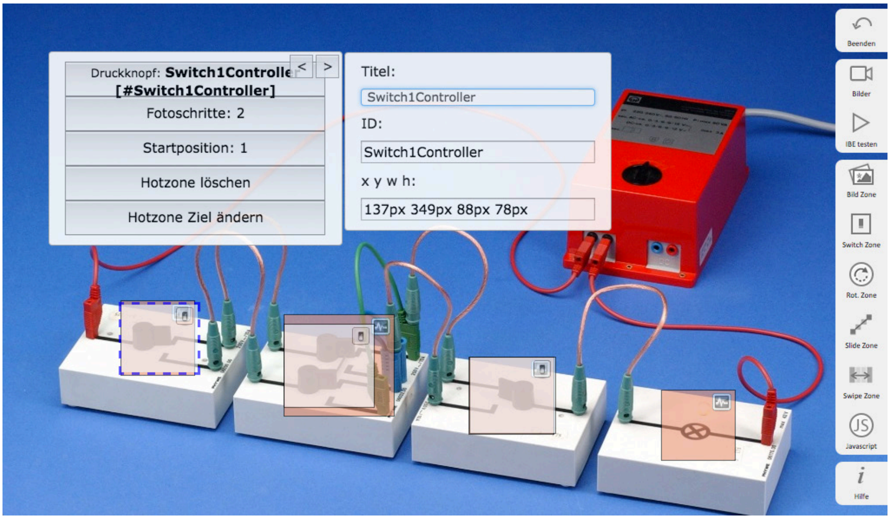

Fig. 5. tet.folio includes the ISE.maker, which turns a series of photos into an interactive screen experiment without requiring any programming experience. After defining interactive regions the user is asked to upload the respective photographs. The regions can be specified by clicking on the screen 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, Almudí, & 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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 237–243). European Physical Society.

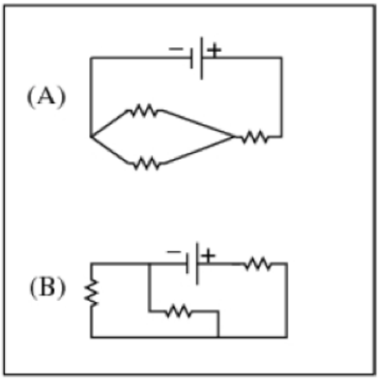

Fig. 1. Circuits corresponding to question Q8 of the pre-test.

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.

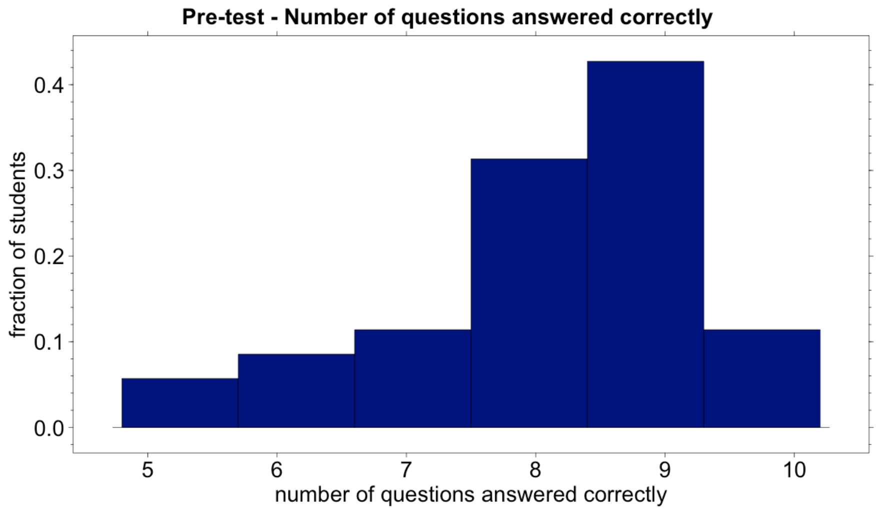

Fig. 2. Number of correctly answered questions out of a total of 10 questions in the pre-test.

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 related 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.

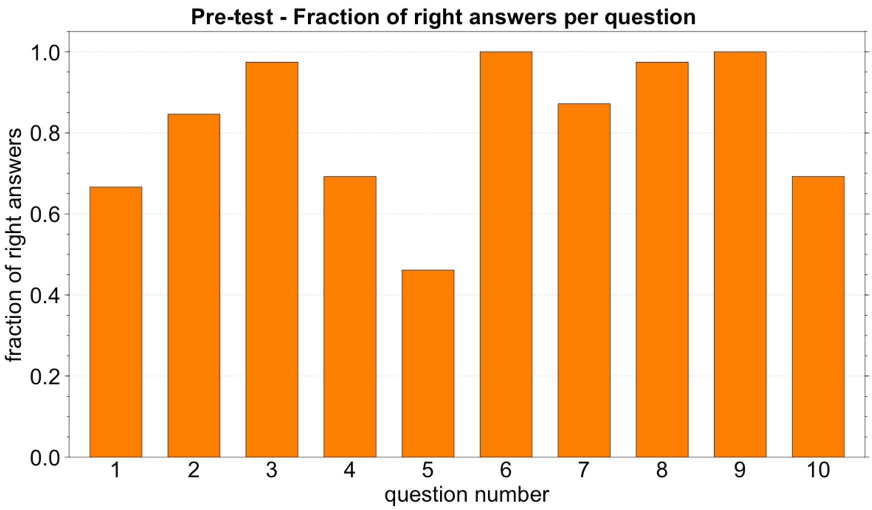

Fig. 3. Fraction of right answers for each of the 10 pre-test questions.

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.

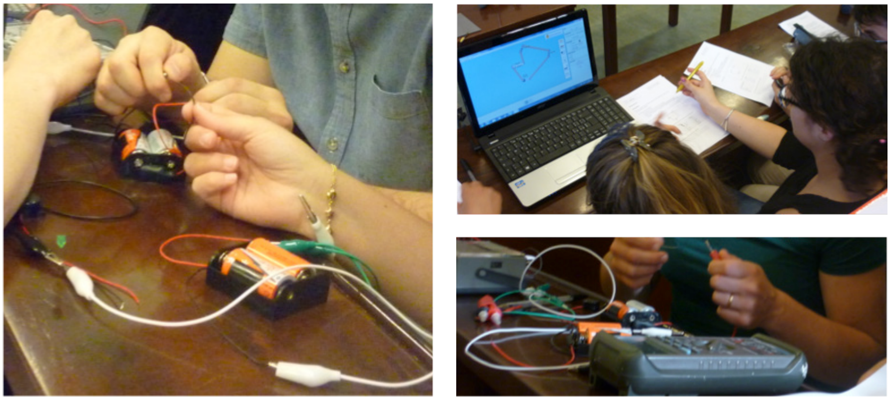

Fig. 4. Hands-on activities (left and lower right) as well as simulations (upper right).

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. 5. 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 then 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).

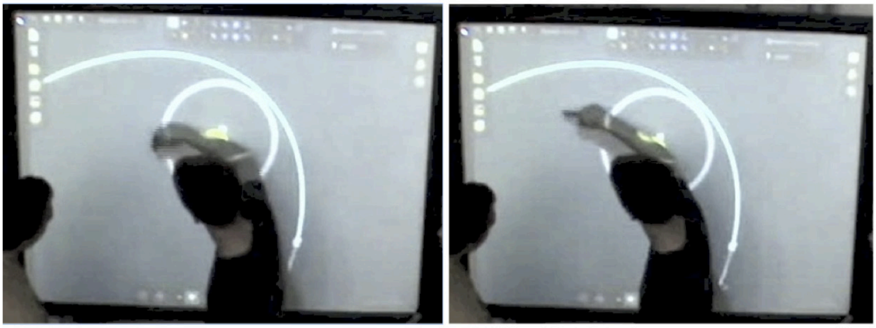
The first gesture (fig. 1) represents an "IWB throw". It conveys the direction and speed of the proposed initial velocity of the object, as well as the throw's spatial location (the throw site). In speech, he accompanies the gesture with two deictic terms corresponding to location ("from here"), and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

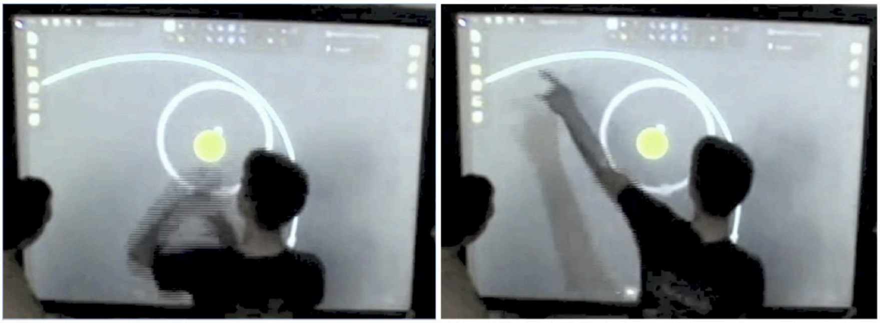
In the last snippet (fig. 3), the student predicts what a new orbit that follows the suggested throw (fig. 1), should look like, based on his hypothesis (which is, itself, based on previous experience with observing and throwing objects into orbit). Once again, the environmentally coupled gesture tells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



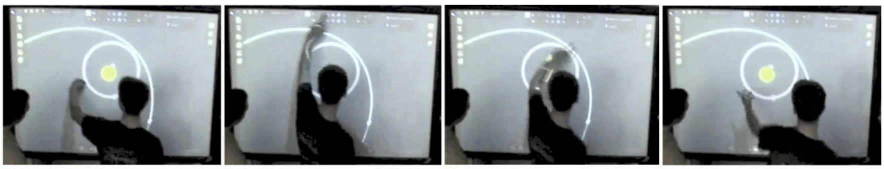
If we threw it from here like this…

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.

Acknowledgements

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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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 253–261). 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' ATPC 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 ATPC 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_{lurk} = 409, N_{post} = 321; def. 2: N_{lurk} = 449, N_{post} = 281; def. 3: N_{lurk} = 480, N_{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 Feinsteins' (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		
Teacher demographics			
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***
Teaching and school characteristics			
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 ATPC 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 ATPC 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.

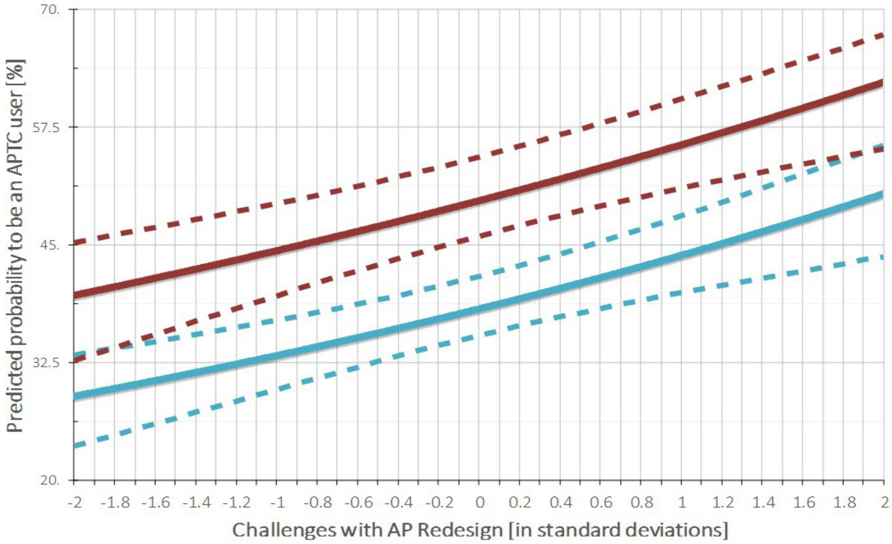

Fig. 1. Predicted probabilities of APTC participation for female (red) and male (blue) teachers with varying degrees of perceived challenges with the AP redesign; the dashed lines represent 95% confidence intervals.

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 ATPC 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 ATPC 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	
Teacher demographics						
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
Teaching and school characteristics						
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
APTC participation characteristics						
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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Preparing Teachers to Use Educational Games, Virtual Experiments, and Interactive Science Simulations to Engage Students in the Practices of Science

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Reform-based instruction emphasizes inquiry-based learning geared towards science and engineering practices. As such traditional science instruction might not be able to fully support students enough to acquire 21st century skills. Implementing digital technologies for learners might provide promising perspectives on how to effectively teach reform-based science. This paper is the result of a technology workshop for pre-service science teachers and provides suggestions on how to integrate educational games, virtual experiments, and interactive science simulations in reform-based science instruction. Besides reflecting on affordances of these digital tools, practical recommendations for teaching preparation are given including how to review educational games for instructional adoption, how to align existing curricular materials supplementary to interactive science simulations to reform-based teaching, and how to develop standards-aligned instructional materials for virtual experiments.

1 Introduction and Theory

When schools are engaged in the adoption of new curricular standards, teachers are often faced with additional external workloads, besides their regular teaching practice. These include the use of new tools and teaching materials designed in response to the changing standards that are intended to foster student learning. Current educational reforms in the United States, initiated through the *National Research Council's Framework for K-12 Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013), promote changes in science education. These reforms emphasize 'inquiry-based' instruction to engage students in science and engineering practices. While traditional forms of instruction might not be sufficient to effectively support teachers in their response to these curricular changes, digital technologies might provide one potential pathway for teachers to advance student learning and achievement (e.g., U.S. Department of Education, 2010, 2013). Good design characteristics of *technologies for learners* include *"support[ing] the needs, goals, and styles of individuals. […] They are designed to be flexible, customizable, and adaptive to learner needs, and are best suited to fit learner-selected goals"* (Halverson & Shapiro, 2012, p. 3).

It is tempting to overestimate the potential of technologies for learners as an influence on student learning. As indicated in the instructional triangle (Cohen & Ball, 1999), materials and technology are necessary but not sufficient elements of teachers' instructional capacity for working with students and content to reach instructional goals. Technology-enhanced learning environments might have the potential to positively impact teachers' reform-based science instruction to facilitate standards-based student learning. Also, digital technologies for learners can support teachers with the adoption of changing curricular

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standards if teachers learn how to integrate these tools in their lesson planning as content resources. A well planned implementation of digital technologies to engage learners in reform-based science instruction can help teachers achieve their goal of engaging students in science and engineering practices. There are many potential benefits of integrating these technologies into the classroom. Potential benefits include access to experiments that are often not realizable in traditional science instruction (due to either expensive laboratory materials or "invisible" conceptual phenomena); immediate manipulation and observation of interactions between variables allowing students to focus on the conceptual knowledge embedded in scientific principles (instead of continuously enacting procedural knowledge, intense activities such as drawing graphs); and individual feedback around science and engineering practices based on personalized student interactions with the learning environment (which is often challenging in real time face-to-face interactions), among many other benefits (e.g., Gröber, Vetter, Eckert, & Jodl, 2008; Joler & Christodoulou, 2001; Moore, Chamberlain, Parson, & Perkins, 2014).

Consequently, we designed a workshop on how digital technologies for learners can act as content resources. The workshop also addressed how to plan technology-enhanced instruction to adopt reform-based science standards, and how to integrate these digital tools in reform-based science teaching.

2 Concept and Implementation

This technology workshop was implemented in the *Teaching Secondary School Science* course for pre-service science teaching interns at the University of Michigan, a large public research university in the Midwest of the United States. In total, 18 pre-service science teaching interns participated in this three-hour workshop. The group of teaching interns was diverse with respect to the school placements for their teaching internships, the respective science disciplines in which they are being certified, and their *content knowledge for teaching* (Ball, Thames, & Phelps, 2008).

When attempting to use digital technologies for learners in science classrooms, teachers need to make numerous decisions while they are planning their instruction. A major question for the pre-service science teaching interns was how to ensure that the technology use is aligned with the lesson's instructional goals and that it supports the intended learning. As such, it became important for the pre-service science teaching interns to learn how to select resources and adopt them towards individual lesson objectives around science content and practices.

Hence, the goals of the workshop were two-fold:

1. Exposing pre-service science teaching interns to a variety of digital technologies and discussing implementation affordances in reform-based science instruction.
2. Introducing a framework to provide a scaffolding of technology adoption teaching practices for effective lesson planning with digital technologies for learners.

The digital technologies for learners presented in this workshop were educational games from *BrainPOP's GameUp* collection (BrainPOP, n.d.), interactive science simulations from the *Physics Education Technology* project at the University of Colorado Boulder (University of Colorado, n.d.), and virtual experiments from the *Remotely Controlled Laboratory* project at the Ludwig Maximilian University of Munich in Germany (Girwidz, Pickl, & Krug, n.d.). The pre-service science teaching interns actively explored each tool through technology adoption teaching practice scaffolds. These scaffolds included strategies for selecting appropriate tools based on teaching objective, aligning and augmenting existing instructional materials towards teaching objectives, as well as designing new instructional materials based on teaching objectives.

The workshop opened with a brief formal introduction of the content and goals. Afterwards, the teaching interns examined the three pre-selected digital technologies for learners. Each examination followed a three-phase structure. First, both the corresponding learning technology and technology adoption teaching practice were briefly introduced

		Standards-based Learning	
		low	high
Gameplay / Engagement	high	Pure games / "Gamification"	Digital game-based learning
	low	"E-learning" / Computer-based training	"Spinach-sundae games"

Tab. 1. Game design classification matrix, slightly modified from Prensky (2006).

by the instructor. Second, the teaching interns were asked to explore the corresponding digital learning environment on their computers in groups of 3-4 persons. Additionally, the teaching interns were asked to enact the corresponding technology adoption teaching practice with respect to the corresponding learning technology. Third, each group presented their experiences with the learning technology and the technology adoption practice to their colleagues. Similarities and differences across group were discussed in a moderated whole-group conversation. After presenting the third learning technology a moderated whole-group discussion reflected on the challenges, affordances, and benefits of implementing the presented digital technologies for learners in reform-based science instruction using the presented technology adoption teaching practice scaffold. Finally, the teaching interns were asked to respond to a short survey with open-ended questions inquiring if, how, and why they might use some of the learning technologies and technology adoption practices in their future teaching.

2.1 Educational Games

Combining the motivational character of games with elements of instruction is seen as a promising direction in educational research in order to enhance students' motivation for learning. "Good" games have several inherent characteristics that are similar to good learning environments. For example, Gee (2005) describes principles of "good" game-based learning environments in the categories of *empowering learners*, *problem solving,* and *understanding.* Learners can be empowered if they are supported to (a) actively co-design their learning experiences; (b) customize their learning based on their own decision-making regarding learning paths; (c) engage in identity building processes; and (d) use tools and technologies that manipulate real world phenomena and enhance knowledge building processes (Gee, 2005). Problem solving is fostered through (a) a well-chosen order of the problems learners face in early learning stages; (b) productive failure; (c) repeated practice and cycles of expertise; (d) information that is available both just-in-time and on-demand; (e) a simplification of systems emphasizing key characteristics of otherwise overwhelmingly complex systems; (f) sandboxes that encourage explorations without risks of failure; and (g) practices situated in meaningful contexts (Gee, 2005). Understanding is facilitated through (a) a "bird's-eye view" on how short-term learning goals fit into the complex structures of the overall learning goals and (b) meaning-making processes that actively reconstruct prior learning experiences (Gee, 2005).

These principles of game-based learning environments can be viewed as "gameplay/engagement" characteristics. Although educational games might incorporate several of these gameplay/ engagement characteristics, in order to facilitate digital game-based learning, the game must also support standards-based learning. An educational game design classification pattern, as described in table 1, can be thought of as a two-by-two matrix that slightly modifies Prensky's (2006) classification of game-based learning.

Unsurprisingly, some criteria that evaluate gameplay/engagement and standards-based learning might overlap. Games that have a high 'gameplay' factor but are low in relation to standards-based learning exemplify gamification (e.g., Deterding, Dixon, Khaled, & Nacke, 2011). This implies that these games are engaging for students but lack support for students to engage with the teacher's specific content objectives. Games that are low in gameplay/engagement, but high in standards-based learning can be thought of as "spinach-sundae" (Jenkins as cited in LoPiccolo, 2004). In this case, the game, like a sundae, may include engaging characteristics, while the content being standards-based is healthy —like spinach. However, when combined, teachers might find that, just like a spinach-sundae, after the initial interest the students do not complete the game, and if they do, students certainly do not want a second helping. On the other hand, if a game has a design that makes use of many of the gameplay/engagement features, while also engaging students in robust standards-based learning of content, teachers can plan on these games motivating students while also being useful for meeting their planned goals for instruction.

One example of an online platform that hosts educational games that can be used in K-12 settings is BrainPOP's GameUP collection (https://www.brainpop.com/games). The GameUP collection can be used in a variety of subjects including science, mathematics, engineering, social studies, English, and others. All games are free of charge and accessible through any web browser. Most educational games are accompanied by content-related animated videos which are offered using a subscription business model. Supplementary lesson plans and other instructional materials are provided on BrainPOP's online platform for educators (https://educators.brainpop.com). However, the instructional materials are organized by topics and focus on the broader content-related goals instead of providing exemplary activities that integrate specific educational games in classroom instruction.

Technology adoption teaching practice 1: Evaluating and selecting tools for instructional adoption

With an increased number of educational games available for every content area, it becomes important for teachers to select digital technologies for learners that are suited to support their instructional objectives. As such, this workshop modeled the technology adoption teaching practice of evaluating educational games based on their potential to continuously engage students in the activities while enhancing learning based on accurate, significant, and worthwhile content. To evaluate the gameplay/engagement dimensions, Gee's (2005) principles of good game-based learning environments were used. To address whether the integration of gameplay/engagement characteristics with the content is addressed, the workshop modeled criterion-based game review processes using the following three prompts:

- *Learning engagement*
  How are learners motivated throughout the game?
- *Learning design and content integration*
  Are scientific ideas represented accurately? How does the game facilitate learning of content and science and engineering practices? What additional guidance do teachers need to provide?
- *Learning assessment*
  How did the game monitor and evaluate learning? How can teachers assess students' learning?

After the review of different educational games from BrainPOP's GameUp collection, a coached discussion was held and recorded on whiteboards to review ideas that were generated in relation to the three criteria above. Furthermore, the pre-service science teaching interns were asked to reflect on affordances and challenges of educational games. For instance, Sarah[1], a Chemistry pre-service teaching intern, stated that she intends to use educational games because *"[…] games are engaging and exciting, and can support learning if used correctly […]."* Similarly, Cheng, a Biology pre-service teaching intern, stated that *"games are fun and it starts them [students] thinking about strategy […]."*

1 Note: Student names have been changed.

2.2 Interactive Science Simulations

Interactive science simulations are tools that provide visualizations of scientific phenomena. Students can explore multiple representations and real world connections through interactive interfaces that allow dynamic feedback. Interactive science simulations have the potential to engage students in explorations that might lead to conceptual understanding, ownership experiences of the learning processes and appreciation of the sciences as accessible and enjoyable disciplines (e.g., Moore et al., 2014; Podolefsky, Perkins, & Adams, 2010).

The Physics Education Technology (PhET) project at the University of Colorado Boulder is a prime example of interactive science simulations (e.g., Perkins et al., 2006). PhET provides interactive science simulations in science and mathematics with content ranging from elementary school through introductory college courses on its online platform (https://phet.colorado.edu). The interactive science simulations are free of charge and accessible through any web browser or a PhET-developed offline program. Supplementary instructional materials are available for each PhET interactive science simulation within the PhET infrastructure. Some of these teaching resources are developed by researchers at UC Boulder, while others were submitted by teachers or other educators.

Technology adoption teaching practice 2: Aligning and augmenting existing materials to support tool implementation

Teachers frequently encounter fully developed third-party lesson plans, curricula, teaching recommendations, worksheets, and other instructional materials to supplement digital technologies for learners that are related to a class they are teaching. However, since they did not design these materials on their own, these materials might not be perfectly aligned with their instructional goals and their specific class and school context. For this reason, teachers need to master the important skill of transforming existing instructional materials into materials that are aligned to standards-based science teaching. In the technology workshop, pre-service science teaching interns adopted instructional materials developed for the *Beer's Law Lab* simulation (https://phet.colorado.edu/en/simulation/beers-law-lab). This interactive science simulation is targeted towards high school students. In this simulation, students can explore relations between the wavelength of transmitted light, the path length through a solution, the solution concentration, and the transmittance and absorbance coefficients (Moore et al., 2014). As part of the workshop, the pre-service science teaching interns reviewed an instructional activity called *Colored Solutions and Spectrophotometers* (Chamberlain & Hendrickson, 2013). Prompts for modifying the existing instructional activity towards better alignment with the *Claim-Evidence-Reasoning framework* (McNeill & Krajcik, 2012) included the following:

- Review the student worksheet for a laboratory session on colored solutions and spectrophotometers regarding connections to the Claim-Evidence-Reasoning framework.
- How could the student worksheet be modified for a better fit with the Claim-Evidence-Reasoning framework?
- Based on your experience working with this PhET simulation, what advantages and challenges might the use of interactive science simulations bring to your classroom?

After sharing ideas for improving existing teaching materials, the pre-service science teaching interns reflected on potential usage of interactive simulations in their own future teaching. For instance, Hope, a Biology pre-service teaching intern, expected to use interactive science simulations because *"students can do a variety of activities with these simulations, such as collaborate with other students, use predict-observe-explain, or a CER [Claim-Evidence-Reasoning] to demonstrate their preconceptions and the knowledge [sic] they develop."* Lindsey, a Physics pre-service teaching intern, observed that interactive simulations *"[…] allow students to connect theory and content to real time phenomena."*

2.3 Virtual Experiments

Virtual experiments are real experiments that can be remotely controlled with a computer with a web browser. Real laboratory experiments are connected through an interface with a webserver. The manipulation of variables on the real experiment is directly observable on the computer screen through web cameras. Some virtual experiments have built-in data collection systems that allow immediate electronic data analysis (e.g., Jia et al., 2006). The integration of virtual experiments in reform-based science instruction allows an interactive use of experimental laboratory set-ups that include digital hands-on experience with authentic science materials (e.g., Gröber, Vetter, Eckert, & Jodl, 2007; Gröber et al., 2008).

The *Remotely Controlled Laboratories* (RCL) project at the Ludwig Maximilian University of Munich in Germany provides 13 different RCLs (http://rcl-munich.informatik.unibw-muenchen.de). The content of the RCLs is targeted towards high school Physics courses. Detailed supplementary materials are provided for each RCL including a description of the experimental set-up, the content background, an analysis of the results of the experiment, and teaching materials such as sample tasks, worksheets, and discussion questions.

Technology adoption teaching practice 3: Developing instructional materials to support tool implementation

Teachers who intend to implement digital technologies for learners in their instruction that do not provide supplementary instructional materials (or that provide inadequate supplementary materials that are incompatible with the teacher's instructional goals) need to develop appropriate instructional materials on their own. In this workshop, the pre-service science teaching interns were asked to develop an outline of an instructional activity for pre-selected virtual experiments of the LMU Munich's RCL project. The following guiding questions were used to plan the instructional activity:

- What variables could be measured? What are the dependent/independent variables?
- What potential hypotheses could be generated?
- How could a data collection and data analysis process look like?
- What state standards or performance expectations of the Next Generation Science Standard could an activity with this virtual environment be related to?

Similarly to prior parts of the workshop, a moderated discussion took place presenting instructional ideas for activities with each virtual experiment while attending to the four guiding questions. Afterwards, the pre-service science teaching interns were asked to reflect on their potential use of virtual experiments in their future instruction. For instance, Joe, a Physics pre-service teaching intern, planned to use virtual experiments in his instruction *"[...] because they are a good way to get students engaged in experiments that may not be possible in a classroom setting."* Similarly, Eryn, a Biology pre-service teaching intern, planned to use virtual experiments *"[...] because they allow students to work with phenomena and principles that they would never get to otherwise."*

3 Discussion and Recommendations

Digital technologies for learners have the potential to both support reform-based instruction and facilitate student learning in the sciences. All described technologies have the potential to support teachers with reform-based science instruction that emphasizes inquiry-based instruction towards science and engineering practices. However, implementations of digital technologies for learners in classroom instruction must be mindful of, and compatible with, teachers' instructional goals.

This workshop offers initial insights on a potential pathway to not only expose teachers to digital technologies for learners but also to support teachers with meaningful technology integration in their science instruction through three technology adoption teaching practices. The scaffold above illustrated how to select digital technologies for learners based on a list of evaluation criteria, how to align and augment pre-existing instructional materials to supplement digital tools towards specific teaching situations, and how to develop new instructional materials that support technology integration.

Evaluating the survey responses indicated that most pre-service science teaching interns described benefits of the technology adoption teaching practices scaffold, as 56%

of the survey responses described the benefits of aligning instructional materials for technology-enhanced instruction with concept development or instructional scaffolds such as the claim-evidence-reasoning framework. Reviewing reflections on affordances and challenges of technology integration, the teaching interns indicated an overall strong inclination to implement digital technologies in their own future teaching as 100% of the survey responses indicated an intent to use at least one digital technology. The interns placed particular emphasis on the benefits of enabling all students to explore scientific phenomena and principles with experiments that might not always be realizable in traditional science instruction either due high costs of the laboratory equipment or practical reasons such as "invisible" conceptual phenomena (as described in 63% of the survey responses.) Teacher interns highlighted this benefit across both interactive science simulations and virtual experiments as described in 73% of the teaching interns' survey responses who identified an intent to use interactive science simulations in their future teaching and 100% of the survey responses from teaching interns that acknowledged their intent to use virtual experiment in their future teaching. Regarding educational games, for the interns who identified they would use educational games in their future teaching, 100% of the teaching interns' survey responses emphasized games as engaging students. Thus, recommendations for providing support to prospective and current teachers that might enable successful technology integration in reform-based science teaching include the following:

- Exposure to a broad variety of digital technologies for learners
- Scaffolded support with technology adoption teaching practices for meaningful implementation of digital technologies for learners in individual teaching contexts
- Opportunities to reflect on technology use with respect to teaching goals

There is potential for digital technologies for learners to enrich reform-based science instruction geared towards 21st century teaching and learning. For this reason, it remains important to continue exploring the determinants of effective educational support toward technology integration in science classrooms.

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Promoting Multimedia in Physics Teaching Through the Flipped Classroom in Pre-Service Education

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A flipped classroom was introduced in pre-service education in order to promote multimedia (MM) and the quality of their use in the teaching and learning processes in laboratory. The course, Physics Lab Didactics, promoted active learning through the direct experience of young teachers. The flipped classroom approach was presented and discussed with the aim of clarifying the teaching process; in-training teachers were invited to explore how to implement this methodology in a class after their experience. Different open source or free software were proposed *(Audacity, Algodoo, GeoGebra* and *Tracker*) with some examples of their use in physics teaching. The discussion on their implementation as tools in physics laboratories was postponed to the last lesson of the course. This pilot study shows great potentiality for flipped classrooms in pre-service education and it indicates that the use of MM in the laboratory learning process can be improved by following this approach.

1 Instruction

The increasing role of technology in contemporary society, as well as the rapid expansion of technology types and uses, requires major changes to teaching methods. The use of a flipped classroom approach in a pre-service course can promote active learning in young teachers, enhance critical thinking and optimise use of student-faculty time together (Keengwe, 2014). This constructivist approach to teaching is an effective means of student-centered collaboration. There are many benefits to this, such as maximizing the opportunities for small group discussion and problem-solving tasks (Larcara, 2014). Moreover, the face-to-face classroom time can be used for peer collaboration, inquiry, and project-based learning (Dickenson, 2014).

Multimedia tools are rarely proposed in pre-service education for physics teachers in Italy.

A pilot study on implementing the use of multimedia is the latest in a series of initiatives to transform teacher practice through professional development (Montalbano, Benedetti, Mariotti, Mariotti, and Porri, 2012). The next section describes the context in which the flipped classroom was introduced; in the following one, its implementation and the materials are reported. In the final section, the results are reported and discussed.

2 Concept of the Teaching Experience

In the pre-service education of Italian physics teachers, the introduction of multimedia tools is usually absent or minimal. Recently, a pilot study with the goal of changing this was realized using a flipped classroom. This implementation helped present several MM to young teachers and to produce educational materials ready for use in schools. Another relevant feature of this teaching experience was the possibility of direct involvement of teachers in a flipped classroom, in order to clarify how this new methodology works. Let us start by describing the context in which the pilot study was realized.

Montalbano, V. (2016). Promoting Multimedia in Physics Teaching Through the Flipped Classroom in Pre-Service Education. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 271–278). European Physical Society.

	pre-service edu Adv. course	Adm exam	Pre-service training	Teaching Qualification
Before 1999	none	no	none	Professorships competitive examination
1999 - 2009	SSIS biannual	yes	290 hours/ year	Exam for teaching qualification (written and oral exam)
2012 - 2016	TFA annual	yes	475 hours	Exam for teaching qualification (final report on training and oral exam)

Tab. 2. Teacher education in Italy in recent decades.

2.1 The Pre-Service Education

Over the last fifteen years, pre-service education has drastically changed in Italy. The main steps in this transformation are shown in table 1. From the complete absence of pre-service training , we arrived at an annual advanced course named Formative Active Training (Tirocinio Formativo Attivo, i.e. TFA) and the process is still ongoing. It seems that the next TFA could be the last one before new reforms are introduced in teachers education.

The first form of pre-service education to be introduced was a biennial advanced school where only basic ICT tools were proposed in a disciplinary context. In the TFA course, the focus on direct training experience led to an increase in the time devoted to training at school and a corresponding reduction in the time available for developing disciplinary and educational skills. Since the use of MM is not widespread in the Italian school system, it in very difficult to change this situation and to promote their integration in current lesson plans.

In this context, the opportunity to increase the prevailing knowledge base in MM through active involvement in flipped classrooms emerged. Moreover, it was the only way to confront this issue in the little time available.

2.2 Participants

The flipped classroom was implemented in a course on Physics Lab Didactics where a special care was given to active learning (Bonwell and Eison, 1991), proposing examples focused on behavior that can facilitate or inhibit it in lessons — especially in lab design and execution. Participants usually had little or no experience in physics labs and active learning was implemented in disciplinary contents (Montalbano and Benedetti, 2013). The focus of the course was on teacher engagement, managing group work, and cooperative learning (Cuseo, 1992). In a laboratory, everything can go in a wrong way or can lead to unexpected results, which can highlight how to interact with students (a lot of good examples happened in the lab; how to manage them was discussed together).

Due to the admission test to the TFA and to the territorial distribution of Tuscan universities, only a limited number of students were enrolled for the teaching program in Mathematics and Physics in 2nd grade of secondary school.

Participant enrolled in the last TFA consisted of four teachers, two with a Physics degree and the others with a degree in Mathematics. Moreover, three of these participants were qualified to teach Mathematics and Science in the 1st grade of secondary school with the previous TFA.

3 The Flipped Classroom

The main purpose was to promote the use of MM in physics education through direct involvement of young teachers in specific tasks. The idea was to show them that learning by themselves how a MM tool works, and then designing and developing new effective materials for the use in class was possible even with little time. Despite time constraints being the impetus for choosing the flipped classroom approach, its pros and cons were discussed in an initial lesson where teachers were encouraged to participate actively.

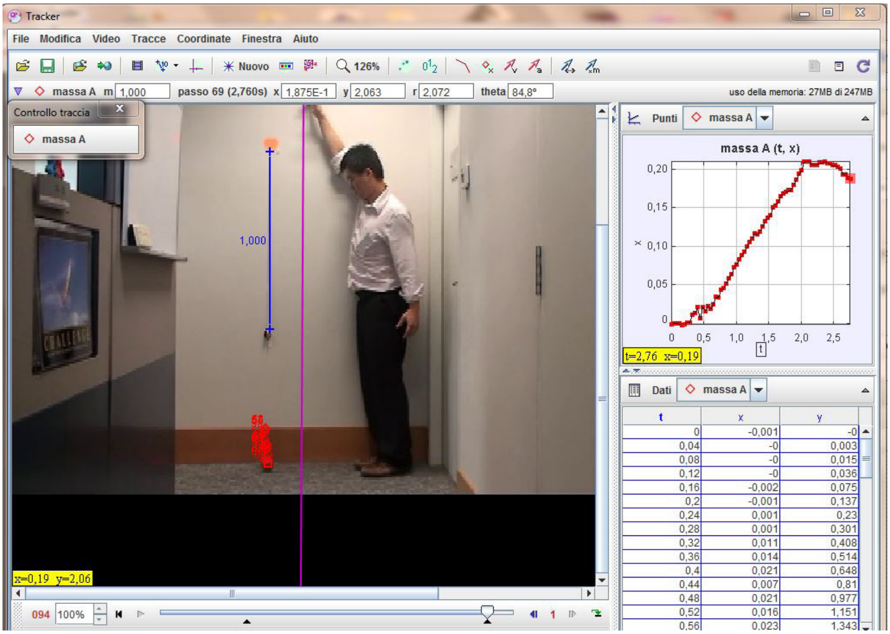

Fig. 1. A proposal was based on a video of the fall and subsequent rebounds of a small ball (the original video was found online by a teacher, Letizia).

3.1 MM Proposals

The first attempt to introduce a MM tool for physics education in pre-service training was done in the previous TFA course (which consisted of about ten participants) by introducing *Audacity* as an example by an interactiveparticipate lesson . In this case, the assessment was disappointing: very weak engagement with teachers and no production of educational materials.

For the flipped classroom, four open-source software (*Audacity, GeoGebra, Algodoo,* and *Tracker*) were proposed. A few words were spent introducing them (where they could be downloaded, how each piece of software could be useful, and so on) and presenting the proposed materials (1-2 examples in PER for each tool).

In particular, for *Tracker*, an exploration of kinematics and dynamics of a game (Rodrigues and Simeão Carvalho, 2013) was proposed. For *Audacity* and *Algodoo*, the examples were taken from the 18th Edition of the Multimedia in Physics Teaching and Learning Conference. An interdisciplinary learning path on sound and noise (Montalbano, 2014) was used for the former, while a simulation for the process of diffusion (da Silva, Junior, da Silva, Viana, and Leal, 2014) was selected for the latter.

Finally, for *GeoGebra*, no additional material was proposed because young teachers attended to another course in TFA where this software was widely used to generate conjectures in dynamic geometry (Baccaglini-Frank and Mariotti, 2010; Leung, Baccaglini-Frank, and Mariotti, 2013).

3.2 Tasks

The goal of maximizing the exploration with the proposed MM tools was achieved by assigning the following tasks to each student:

- Choose a different MM tool (promote cooperation in organizing the tasks);
- Learn to use the MM tool (require active learning);
- Design a learning path related to a physics lab topic where the MM tool can demon-

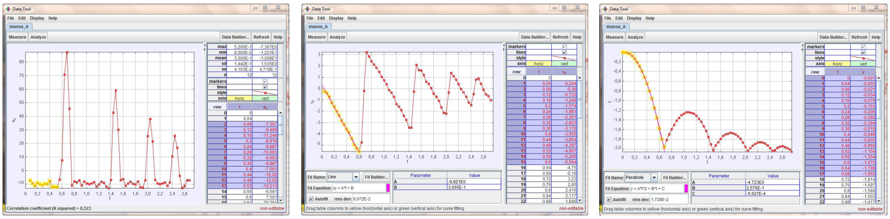

Fig. 2. The figure shows screenshots for some activities proposed in the lesson: the vertical position in the time (on the left), the vertical velocity (in the center) and the vertical acceleration (on the right). In each screen, the data points for the initial falling are selected (in yellow) and shown on the right. The fit for the selected data is shown below for the position and velocity..

strate effective assistance in the learning process and implement it in details (promote active learning in teaching skills);

- Share his/her learning path with peers with explicit remarks on methodological choices, and the strengths and weaknesses of the use of the software (maximum dissemination of MM and learning paths).

The peer sharing was realized in a lesson through an interactive presentation; written worksheets for each proposed learning path were mandatory.

4 Results and Remarks

The main goal achieved with the flipped classroom was the interaction between teachers who had already actively used the software in an educational context. The materials produced were discussed both from the perspective of the learning process and the characteristics of the software. All materials were shared in a cloud storage service whose link was created and shared by teachers.

Each teacher presented a different learning path: a study of a falling body using available software as a tool for measuring and fitting from a video (Letizia), a simulation of different situations in a gravitational field on the Earth's surface to verify a Galileo's theorem (Riccardo), an analysis on different sounds to explain their features and introduce resonance (Stefano) and an interdisciplinary path on the Huygens' pendulum (Mauro).

4.1 On Studying Dynamics with *Tracker*

The proposal is a standard laboratory experiment for exploring the dynamics of a falling body but it was performed by analysing a video using *Tracker*.

A screenshot from the analysis is shown in fig. 1. The video showed a small ball falling and rebounding several times as shown in the complete analysis given in fig. 2, where the vertical position, velocity and acceleration measured from the frames are shown as a function of time.

Moreover, first falling data were selected and used to fit the acceleration of gravity g in two different ways: by using a parabolic function for the position and linear regression for the velocity. Both results are shown in fig. 2.

The discussion focused on the use of the MM tool, about some difficult in measuring, the evaluation of uncertainties and the quality of the fitting tool.

Finally, the possibility of studying collisions, especially from perspective of energy, was explored.

4.2 Verify a Galileo's Theorem with *Algodoo*

"Algodoo is a physical simulation program, very similar to a game. Objects of any shape are easily created, with the difference they suddenly become "real" in the physical world simulation, for example, as soon as they are created, we see them fall to the ground" (from description of the software by Riccardo to other teachers).

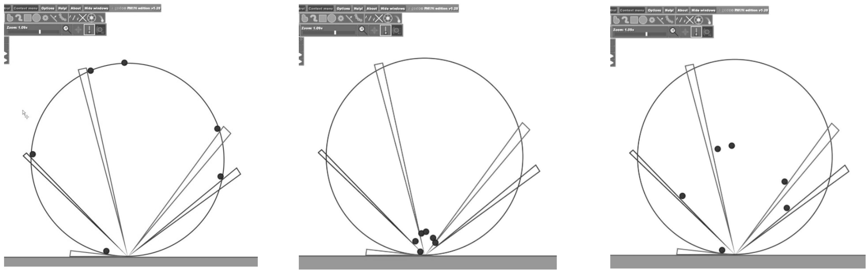

Fig. 3. The figure shows program screenshots for the activity proposed for "discovering" Galileo's Theorem.

The use of the above software in physics and mathematics education was promoted by Riccardo in this way: *"How many interesting experiments are never realized because the result is not worth the time spent to prepare them! The simulation allows us to recover with ease, precision and relative speed at least some of these experiences. Thus, I propose this activity: it is easy to make and shows a spectacular effect that leaves those who do not already know the result amazed. The activity is useful for concepts and questions that can be articulated, and it bypasses exercises that would require hard work to complete it. . . and it was based only on falling bodies!"*

A limitation to the software was pointed out: introducing a variable field of force was not possible. This excludes using of the software to simulate celestial mechanics or the motion of electric charges. The teacher tested another software with this possibility (*Step*) but he encountered too many bugs and his opinion was that it is still not ready for use in schools. *Algodoo*, conversely, is fully ready.

4.3 A Learning Path on Sound and Music with *Audacity*

The learning path proposed by Stefano focused on the characterization of sounds through a software audio editor. The proposal consisted in giving to students audio composed of various tracks, synthesized by the teacher and characterized by different frequencies and different waveforms (sine, square, saw tooth, see fig. 4). Students must characterize each

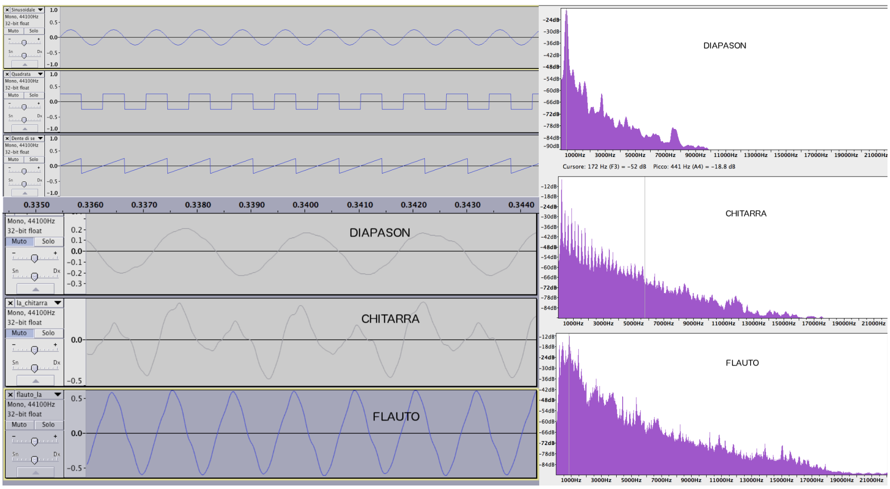

Fig. 4. The figure shows program screenshots for the initial activities. The sound tracks prepared by the teacher (on the top of the left side) and obtained by recording sounds from a diapason, a guitar and a flute (on the bottom of left side), whose spectra are shown on the right side.

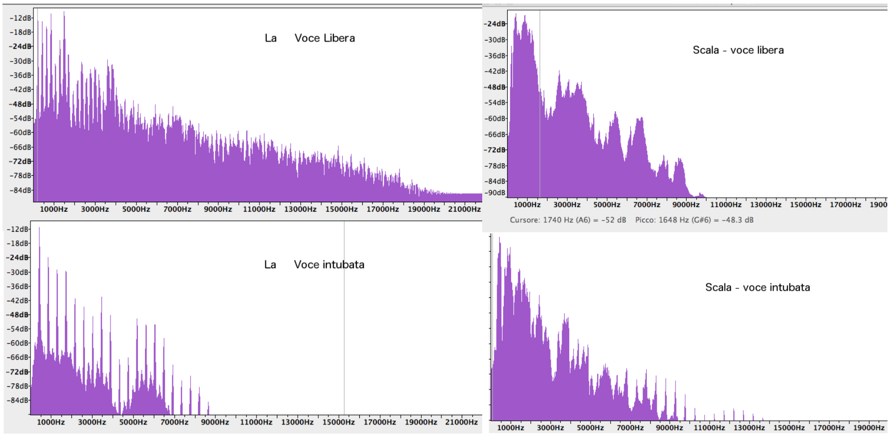

Fig. 5. Spectrum obtained by analysing a free human voice pronouncing a vocal (top left), inside an open tube (bottom left) and the spectrum of a human voice singing a scale (top right) and the same sound inside an open tube (bottom right).

track quantitatively, study the waveform (time domain) of each track (measuring amplitude and sampling frequency), and the spectrum of each track (frequency domain) by finding the peak and width of its frequency distribution. The next step is a general analysis of feelings derived from the combination of different tracks: which of these tracks sounds harmoniously? which are dissonant? which look very similar? Is there any law that governs the similarity between frequencies of the sounds? And among their harmonics?

The following activity is the study of recordings of individual notes produced by various instruments (guitar, flute) and mechanical oscillators (diapason), whose soundtracks and spectra are shown in fig. 4. What tools emit more “simple” sounds? Which ones are more compound?

The last activity is the study of human voice by singing a note and recording a single vocal track. The resulting spectrum is then compared with the case in which sound enters in an open tube (Hula Hoop). All spectra are shown in fig. 5.

The spectra shown in fig. 5 were generated by the teacher during the peer presentation with the aid of Stefano’s daughter (who was about ten years old). The involvement of his family in the research of useful and easy activities that can be realised at school showed its full interest and engagement in the topic.

4.4 An Interdisciplinary Learning Path on the Huygens’ Pendulum

The last proposal was more clearly articulated, interdisciplinary and interesting. The purpose was to compare a pendulum with a Huygens’ pendulum from a theoretical and experimental perspective. Thus, it was necessary to construct and verify the isochronism of a Huygens’ pendulum but also to demonstrate the interesting properties of a cycloid function in a high school class.

In order to verify all property of a cycloid, dynamical demonstrations were constructed by using *GeoGebra* (see a frame of the demonstration of the involute in fig. 6).

The Huygens’ pendulum is a historic example of the relationship between mathematics, physics and technical progress that introduces complex relations that bind science and society. In figure 6, a picture of the pendulum from the original proposal of Huygens and a details of Huygens’ chops following a cycloid shape in an ancient clock are shown.

GeoGebra allows to generate a print of a cycloid adapted to shape Huygens’ chops in wood (see fig. 7 for relevant steps in the construction of the pendulum).

The final device was optimized for video analysis with *Tracker* choosing an effective shape and colour for the pendent mass. An example of measurement is given in figure 8.

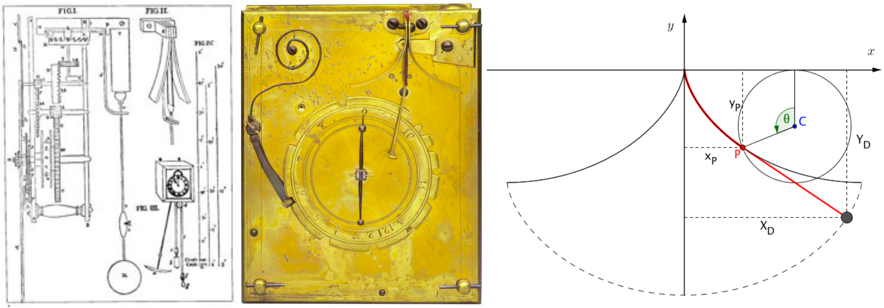

Fig. 6. The original figure (Huygens 1673) with the proposed pendulum mechanism by Heygens (on the left), details of Huygens' Chops in an ancient clock (in the center), and the cycloid function and its involute from a frame of the dynamics demonstration constructed by *GeoGebra* (on the right).

Fig. 7. Two steps in the realisation of the Huygens' pendulum: the use of printed cycloid from *GeoGebra* (on the left side) and the levelling of the device (on the right side).

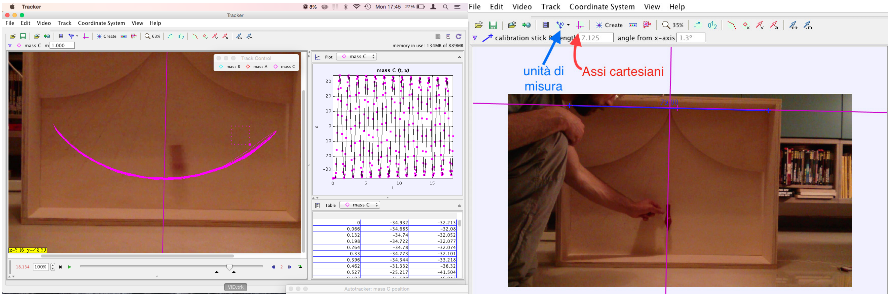

Fig. 8. The measure with *Tracker*: Positioning the axis in the initial frame (on the left) and a sampling of measures (on the right).

The devise was very versatile, allowing for measurement with a pendulum and Huygens' pendulum. It was possible to move the two pendula simultaneously and observe almost no difference with small initial angles, and yet a clear asynchrony when initial angles are larger.

The most interesting aspect from the experimental point of view was the sensitivity of the device when used with *Tracker*. The isochronism of a Huygens' pendulum was tested for initial angles in the range of 15°- 50° and the resulting period was always measured to be the same: 1.35±0.02 s.

4.5 Remarks and Conclusions

The main goal achieved with the flipped classroom was the excellent engagement and the active response from teachers. Their full involvement led to animated and interesting insights in the use of the programs in the classroom and in the laboratory. Another important aspect was the acquisition of the awareness that the use of multimedia tools can effectively improve the educational action and that it requires an acceptable undertaking in terms of time and effort. Direct assessment was performed during lesson time, laboratory and MM products were shared together with new ideas and educational materials, maximizing the available time.

Teachers developed good ideas which led to realizing well-designed specific learning paths. Moreover, discussions on the use of MM arose during the physics laboratory. A creative use of *GeoGebra* emerged during data analysis to measure the time of discharge of an RC circuit. (Montalbano and Sirigu 2015).

The success of the teaching experience depends on careful choice of the initial materials proposed for the flipped classroom and a well-established student-teacher relationship (e.g. trust gained in the previous TFA course). This is necessary to avoid the first —and often apparent— impression of students once the flipped classroom is proposed: the teacher is lazy and is avoiding his/her responsibilities.

Another relevant factor is the small number of participants and the fact that they were graduate students sincerely interested in the professional development of their skills. Moreover, the chosen topic, MM tools in Physics education, was very well-suited to the interest and the wealth of materials available. Last, but not least, the participants were excellent students who formed a very good working group, and will hopefully become excellent teachers.

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The Use of Digital Technologies in Physics and Mathematics Education by Partnership Pedagogy

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In recent years, significant changes have taken place in the world, especially in Information and Communication Technologies (ICT). Students in this field are increasingly dealing with advances in ICT. However, these changes are still poorly appreciated in Brazilian public schools. We realize that the traditional way of teaching can lead to discouragement, lack of interest, and increasing in problems such as avoidance, unruliness and failure. In stark contrasting to the to the embracement of students, there is still some resistance among teachers to the adoption of digital technologies in the classrooms. Using the Presnky´s Partnership Pedagogy and low cost materials, this study aims to promote sharing of information between teachers and students through the use of Vernier Video Physics applications and the Vernier Graphical Analysis tool, in studying the launch of projectiles.

1 Introduction

Over the last thirty years Brazilian society has watched the country go through many political, economic and social changes; the most prominent of all, however, have been the changes in Information and Communication Technology (ICT). Despite the increased influence of ICT on the daily lives of average citizens, the influence of ICT on the education being offered in public schools, has been slow to develop. School administrators need to understand that along with new technology, students' perspectives have also changed. Nowadays, students live with technology in their daily routine. They make increasing using of their cell phones and computers, they interact in virtual environments, they are becoming leaders in these environments and, especially, they are searching and selecting knowledge that attracts them. This participatory behavior, however, is seldom observed in the classroom. School has stopped being interesting for these "new" students. Despite the ever-increasing integration of technology in people's lives, schools still do not include the integration of this type of technology into their planning of the classrooms. Instead, the same old model is preserved. Another problem found in many schools is the resistance of some teachers to this integration. The reasons for such resistance have several origins. For example, insufficient preparation time for planning, lack of sufficient materials for a large number of students in the classrooms, slow internet connections, and, particularly, the lack of skills in using the technologies arriving at the school. According Giraffa (2013), teachers who simply refuse to consider the use of ICT in their activities with students, are at enormous risk of speaking without being heard. As a solution to this problem, Prensky proposed the Partnership Pedagogy, whereby the students teach their teachers to use these technologies, allowing the teacher to extract the pedagogical potential of these technologies and improve their classes.

There are several published papers on the introduction of ICTs in the classroom, but in practice we almost do not notice their inclusion in the school, especially in the public

Araújo, F. A. G, Oliveira, M, M., & Nobre, E. F. (2016). The Use of Digital Technologies in Physics and Mathematics Education by Partnership Pedagogy. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 279–283). European Physical Society.

Fig. 1. A student shows to a teacher how to use the application Vernier Video Physics and Graphical Analysis.

schools where the precariousness or even the absence of such technologies, is observed.

1.1 Objectives

Based on the Partnership Pedagogy and using low-cost materials, the main objective of this study is the sharing of knowledge between teachers and students through the use of Video Review applications for the study of functions. Specifically, we intend to:

- give students the opportunity to participate in the teaching and learning process;
- decrease the separation between theory and the student's everyday experience;
- insert ICT in daily school lessons;
- Facilitate dialogue between teachers and students.

2 Methodology

The project was developed in a public secondary school, located in Fortaleza, Ceará, Brazil, with the participation of teachers of Physics and Mathematics and high school students.

Rockets were built with matchsticks and their releases were filmed. The students taught the teachers how to handle the applications, to analyze the video of the rocket launches.

We conducted workshops with teachers and students and then we applied a questionnaire to all participants

2.1 First Workshop

The first workshop was held at the science lab. Teachers and students built rockets using low-cost materials, such as:

- matchsticks (two matchsticks for each rocket),
- aluminum foil,
- barbecue stick (one for each rocket)
- metal clips.

Each teacher filmed the launch of their rocket using a camera from a tablet with an acquisition rate of 30 fps (frame per second). The goal was to analyze the video later with the Applications Vernier Video Physics (VVP) and Vernier Graphical Analysis (VGA).

2.2 Second Workshop

In the second workshop, students demonstrated to teachers how the applications worked, so that they could manage these applications and perform video analysis of the launch of the rockets. The figure 1 below shows a student explaining to a teacher how to use the application.

In figures 2 and 3, we can see a student and a teacher, respectively, launching their rockets.

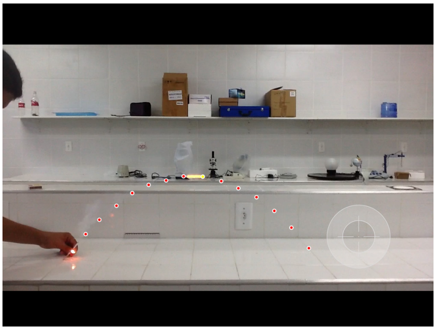

Fig. 2. The student launching his rocket.

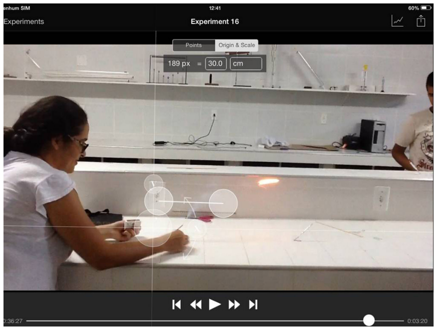

Fig. 3. A rocket being launched by a teacher.

3 Results

With VPP and VGA, teachers could plot position and speed against time. The VGA application, provides more accurate data on the movement of the rocket, such as its trajectory, its maximum and minimum speed, its maximum height, a trendline of the motion data, and the error between the measured and ideal trajectories. The application receives the data and generates the graphics for position and speed, as shown in Figures 4 and 5.

The graphs were analyzed by the teachers and discussed with the students who conducted the workshops. It was also debated whether to use this kind of methodology in the classroom was efficient.

After the workshops, the teachers answered a questionnaire containing five questions:

1. Have you made use of any type of application in the classroom?
2. Did you encounter any difficulty in handling the RGB and VGA applications?
3. Do you believe that the use of applications in the classroom could enhance learning Physics and Mathematics?
4. Have you used the RGB and VGA applications in the classroom?
5. What difficulties do you think you or your students might face in carrying out these workshops in the classroom?

The objective of the questionnaire was to learn more about the teachers, what they thought of using technology in the classroom and what they thought about the workshops they participated in.

The responses to question number one showed that almost 60% of teachers had never used applications in the classroom. Half of these 60%, said they had difficulty using this kind of technology because of the large number of students in the classroom. One teacher said he had never researched the use of such classroom resources. Just one teacher said that even not using applications, he already had used mathematical programs like Kinplot, Geogebra and Eletronic Spreadsheets. Although these programs are important tools, they do not permit video analysis of real motion in a rocket launch, for example, as we did. They also do not permit comparison between real and idealized movement. This is an important and necessary consideration which goes far beyond mathematical calculations.

In response to the second question, 30% of teachers said they found it difficult to handle the VVA and VGA applications.

In response to question three, the teachers were unanimous in saying that the use of applications in the classroom could improve learning Physics and Mathematics.

In question number four, we asked the teachers if they had ever used the RGB and VGA applets in their classrooms. All of the teachers said they had never used such applications in their classrooms. They presented various reasons for this, such as, lack of opportunity, difficulties due to too many events at the school and others. Just one teacher said he intended to apply the applets in their classes still in 2015.

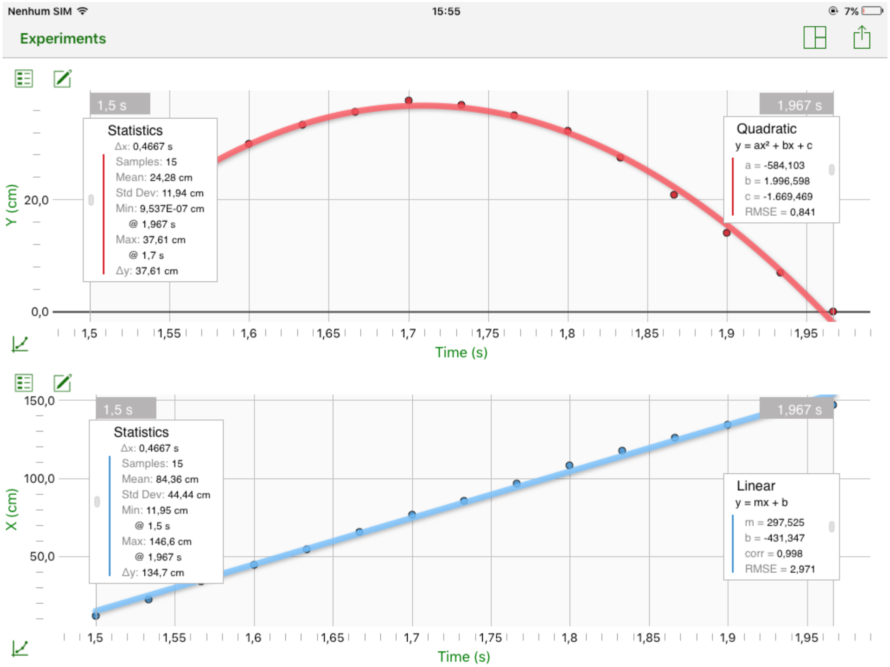

Fig. 4. Graph of rocket position coordinates generated by the VGA application.

Finally, in the fifth question, we wanted to know what difficulties the teachers believed that they and their students would face in holding the workshops in their classrooms. About 42.85% of teachers said they would have no trouble, and they believed that students would like it very much. Approximately 28.57%, said that unruliness and lack of interest from some students in studying science could harm the workshop. The remaining 28.58%, mentioned the difficulty of using the applets, due to the large number of students in the classroom.

4 Concluding Remarks

In addition to proposing the use of applications and video analysis in studying mathematical functions used in Physics, this work proposed the opening of dialogue between students and teachers through Prensky´s Pedagogy of Partnership. High School students were able to share knowledge about new technologies with their teachers, so that they could use them in the service of education. The results and observations lead us to reflect on some important points; teachers who participated in this work showed up fully prepared to learn what their students were proposing and participated actively in all activities, although the proposal has not yet been replicated in the classroom. The workshops with the use of low cost materials, and ICTs, can give more substance to the subjects studied by students. In this case, the content requires mathematical functions, making the lessons dynamic and interesting. In addition, the workshops can contribute to enhancing lessons in schools that do not have science laboratories.

Analyzing the questionnaire applied to teachers, we found that 60% of them had never used any kind of applets in the classroom and half of them had difficulties in using this kind of technology in the classroom. Despite their difficulties, all of them said that workshops using low cost materials combined with new technologies may facilitate the learning of not only Physics, but also the mathematical functions needed to study the launching of projec-

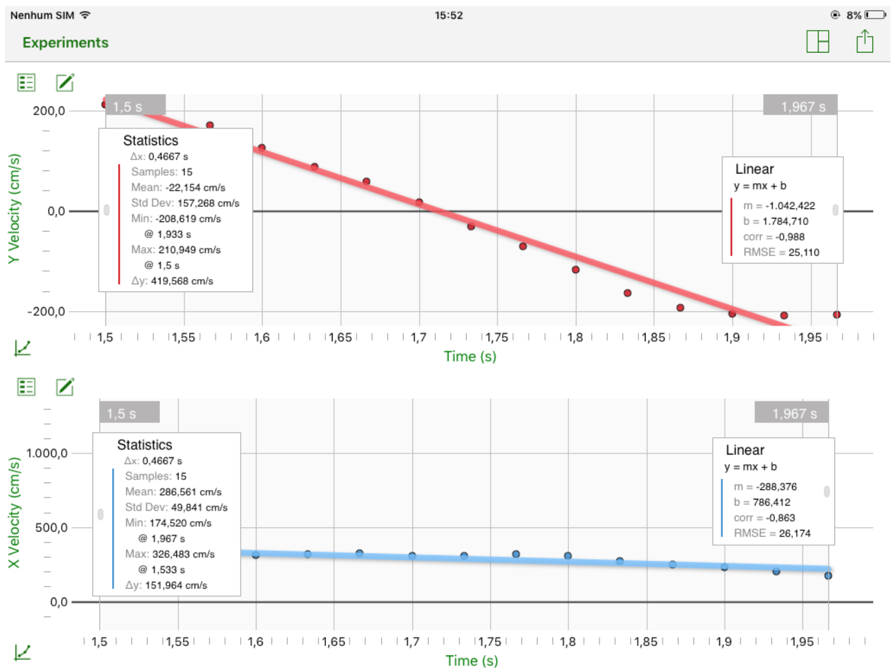

Fig. 5. Graph of rocket speed generated by the VGA application.

tiles. This makes the classes more dynamic and interesting, in addition to being excellent alternatives for schools that do not have appropriate science laboratories. Teachers also said they did not feel their authority was diminished by learning with their students and that this exchange of knowledge helps to improve the processes of teaching and learning because the students themselves feel involved in the process.

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Design and Practice of an In-Classroom Moodle System Supporting for Self-Teaching in the Elementary Physics Education in University

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An original review-test system for elementary physics in the classroom has been developed at our university for the purpose of the acquisition and the retention of basic knowledge in this area. The underlying concept of this review test is to reactivate knowledge before starting classwork since quite a number of students are always forget what they learned in previous classes. The review test is implemented in the learning management system, Moodle. In this study, an elementary physics course offered for second-year students was the subject under investigation. During the review test, students always refer to the text, their notes and other reference materials for reactivating sufficiently what they learned. It takes approximately 15 min. The effect was examined using a pretest and posttest for basic knowledge and was also examined by Force Concept Inventory (FCI). It was confirmed that the basic knowledge was retained sufficiently, though result of FCI was not sufficiently improved.

1 Introduction

The percentage of high school students enrolling in universities has increased gradually and it reached more than 50% in Japan (Ministry of Internal Affairs and Communications of Japan, Statistic Bureau, 2015). Accordingly, many Japanese universities have to take on students who do not have the necessary academic background. In physics education, many new students lack familiarity with basic concepts and knowledge of the discipline. In particular, private universities have marked tendency of this issue. In Japan, private universities account for about 77% of all universities (Ministry of Internal Affairs and Communications of Japan, Statistic Bureau, 2015). For this reason, many private universities cannot avoid accepting a considerable number of such students. This is a serious issue which must be improved.

Increasing university enrollment rates is not only an issue in Japan but also in other countries. In Australia, United States, United Kingdom, Germany, Korea and many other countries, enrollment rates is over 50%, while the of OECD average is approximately 60% (OECD, 2014). This tendency is typical of many these nations. The issue of improving academic standards in universities will continue to be a serious problem for many nations. In United States, many universities have grappled with this problem for many years (Boylan & White, 1987; Van, 1992; Higbee, Dwinell & Thomas, 2002).

Although active learning has a relatively long history as an education methodology, it has received particular focus in recent years. Active learning promotes deep understanding and stimulates spontaneous willingness to learn in students. Many teachers have begun trying to adopt active learning practices in their classes recently. However, basic knowledge such as basic physical quantities, units of them and so on, is necessary to be effective. If active learning is adopted in the classes with students who lack of basic knowledge, sig-

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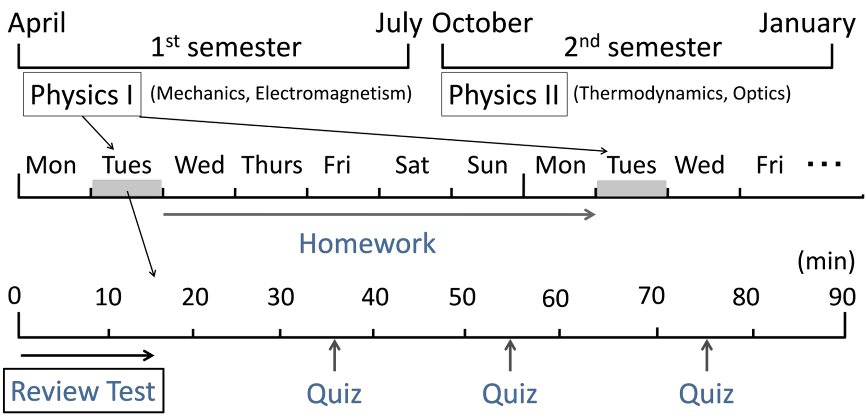

Fig. 1. Course schedule of Physics I and Physics II over two semesters.

nificant benefit cannot be expected. In such classes, improving fundamental knowledge is prerequisite for active learning.

An original review-test system for elementary physics in classrooms has been developed in our university in order to improve background knowledge in students (Anada, 2009). The effect of the review-test on academic ability in physics was examined by a regular test at the end of semester in our university. As a result, it was confirmed that the review-test was useful for retaining the fundamental knowledge. Afterwards, in order to develop practical use of the review-test, the review test was implemented in the learning management system, Moodle (Anada, 2014; Anada, 2015). In this study, the effect of the review-test is reconfirmed by investigating data collected after the previous study. Finally, the effectiveness and the limitations of the review-test are investigated by the pretest and the post-test, the regular test at the end of the semester and by the Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992).

2 Course Schedule for Semester

The class Schedule in two semesters is shown in Figure 1. The elementary physics course has two subjects, Physics I and Physics II. The former includes mechanics and electromagnetism and is available in the first semester. The latter includes thermodynamics and optics and is available in the second semester. These courses are offered to the second-year students of Hokkaido Information University. Students can take one or both of these subjects. The content of both the subjects is elementary physics as liberal arts. Each subject of Physics is composed of 15 classes in one semester. Each class takes 90 min and is offered once a week. The review test is taken at the beginning of the class to remind students of the content from the previous week. The important point is that the class starts from the review-test. In the class, a short quiz is offered approximately every 20 minutes and homework is assigned. However, it was confirmed that the review test is the most effective way to ensure memory is retained (Anada, 2009). The quiz is considered effective in keeping the concentration of students and in aiding their understanding of physics concepts.

3 Review-test

3.1 Paper Based Review-test

The goal of this review-test is to remind students of the contents of the previous class. For this reason, students always refer to the text, their notes and other reference materials

Physics Ⅱ The 6th Review Test

Department	Class	Student ID	Name

Chose the suitable answer from the CHOISES.

	Meaning of terms		Formulas, Symbols	
Internal energy of ideal gas	1		4	
The 1st law of thermodynamics	2		5	
Principal of a heat engine	3		— —	———
State quantity	—	———	6	
			7	
			8	

〔CHOISES: Meaning of terms〕

[1] The law which means the work is equal to the heat.

[2] The fundamental quantity representing the amount of material. It is counted by the unit of the Avogadro number.

[3] Internal energy a system increases if the heat or the work is took out from the system.

[4] The ability of working which occurs by keeping a distance between the attracted objects.

[5] The internal energy of the ideal gas is inversely proportional to the absolute temperature.

[6] The internal energy of the ideal gas is proportional to the absolute temperature.

[7] Internal energy of a system increases if the heat or the work is given to the system.

[8] Taking out the work from a system by using thermal expansion of material.

[9] The energy necessary for heating a material of 1 g by 1℃.

[0] The relationship between the volume, the temperature and the pressure.

〔CHOISES: Formulae, Symbols〕

[1] $\boldsymbol{Q}$

[2] $PV = nRT$

[3] $\boldsymbol{\Delta U} = \boldsymbol{Q} + \boldsymbol{W}$

[4] $\boldsymbol{U}$

[5] $\boldsymbol{U} = \frac{3}{2}\boldsymbol{NkT}$

[6] $\boldsymbol{W}$

[7] $\boldsymbol{V}$

[8] T

[9] $\boldsymbol{J}$

[0] N_A

Fig. 2. An example of paper-based review test (The original test is written in Japanese)..

Fig. 3. Interface of review test (in Japanese).

during the review-test. However, students must do it alone without asking for help from other students. The important point is that students should recall faded memories from their mind by their own efforts.

The review test is consists of two parts, as explained in the previous paper (Anada, 2015). One part focuses on definition of terms. It reviews understandings of fundamental laws of physics and the comprehension of physical phenomena. The other part reviews formulae and symbols. The review test was originally administered on paper. Students submit a mark card with their answer entered. An example of the review test is shown in Figure 2. It takes approximately 15 min for students to work through the problems, including time for collecting the mark cards.

3.2 Moodle Based Review-test

The medium of the review test has changed from the paper-based system to Moodle (Modular Object-Oriented Dynamic Learning Environment) which is a kind of learning management system in e-learning (Dougiamas, 2015). A screen shot of the interface of the Moodle-based review test is shown in Figure 3. Equations and symbols in the test are made using TeX (Goossens, Mittelbach & Samarin, 1994). Example source code from one of these TeX files is shown in Figure 4. In the Moodle-based system, a space for students to write down their comments about their results of the review test was also implemented. It is known that looking back in order to process experiences is useful to provide motivation for action to next step. The looking back often causes metacognitive reflection which makes people to grow. The Moodle-based system makes it possible for students to process their test results by writing down their comments just after taking the test. Furthermore, the Moodle-based system makes it possible to accumulate the description data. We can use these data for making analysis of their looking back using the text mining method.

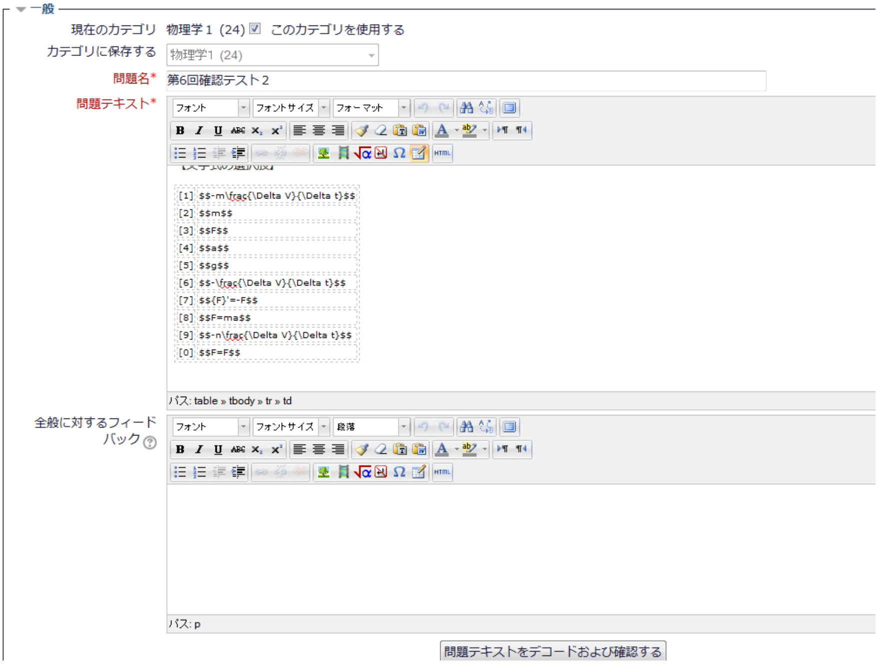

Fig. 4. TeX source code of the review test (Center part in this Figure).

The reasons for changing the review test from the paper-based system to the Moodle-based system are that the new media provides the following benefits (Anada, 2015):

1. Immediate marking
2. looking back and metacognitive reflection
3. Accumulation and analysis of test results and looking back text data
4. Reduction of teacher burden

Regarding the 1st goal, the immediate marking and return of the result to the students is difficult in the paper-based test, even though a device is used to read mark card. Results are returned one week later at the earliest. Conversely, in the Moodle case, the review test is marked immediately. As the students are able to check their results immediately, they can naturally reflect on their answers. A function for entering reflections in the Moodle-based review test makes students' reflection easier. This relates to item number 2, above. As mentioned in item number 3, the results of the review test are accumulated automatically in the Moodle-based system. Because of this, it is easy to analyze the results. Finally, the 4th reason for using Model is to reduce the burden on teachers. This does not imply negligence. Faculty members are very busy with their many responsibilities; this includes teaching many classes, marking homework, attending many meetings and affairs of faculty and university staff, and so on. Reducing this burden helps make a sufficient time available to educate students.

4 Effect of Review-test

The paper-based review test was introduced in 2005. The results were observed immediately, as described in the previous paper (Anada, 2009). The results were confirmed by improvement in the average grade of the class in the term examination. The average grade increased 10 points out of 100 in Physics I and 25 points in Physics II on average. Although the average mark in 2002 in Physics II is high, it is exceptional because there were very

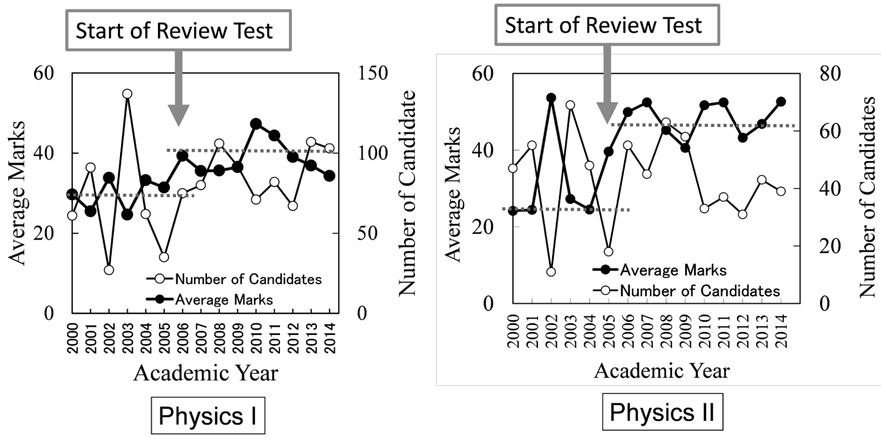

Fig. 5. Average marks and number of candidates for the term examination of Physics I and Physics II against academic year. Filled circles are for the average marks and open circles are for Number of students.

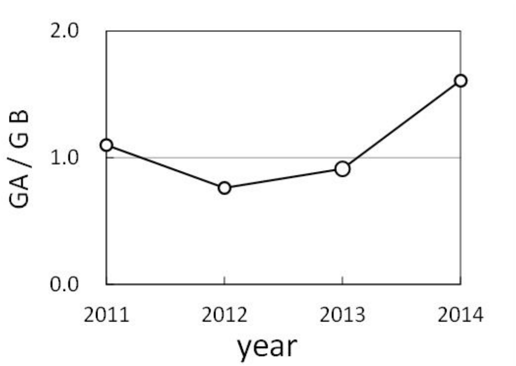

Fig. 6. Ratio of the gain for Group A (GA) relative to that of Group B (GB) in the class of Physics I against academic year.

few students in this year, less than 10. Verification of the effect of the review test has continued up to the present, since the publication of the first study (Anada, 2009). The results are shown in Figure 5. The average grade of Physics I in these two years is relatively low. However, as the marks in Physics II increase, it is assumed that the data in these two years are within the range of variation. Consequently, the benefit has persisted, though further investigation is needed.

5 Result of Pretest and Posttest for retaining Basic knowledge

In order to examine the effect of establishing basic knowledge, pretests and a posttests were carried out at the beginning and end of the semester respectively. As discussed in the previous study (Anada, 2015), the students (Group A) who took the Moodle-based review test obtained higher scores than the students (Group B) who took the paper-based review test. The result is shown in Figure 6. A gain G of the posttest over the pretest is defined by the following equation.

Academic Year	group	pretest	posttest	G
2014	whole class	10.5	11.7	0.04
	Moodle (Group A)	10.7	11.8	0.04
	paper (Group B)	10.1	11.3	0.06
2013	whole class	8.7	10.9	0.09

Tab. 3. Results of FCI pretest and posttest in the class of Physics I together with the FCI gain G.

Figure 6 shows the ratio of the gain of the Group A (GA) to that of the Group B (GB). Before 2013, the students of both groups took the paper-based review test, since there was no Moodle-based system available. In 2014, however, the students of Group A took the Moodle-based test and the students of Group B took the paper-based test. Although Group A and Group B have almost the same value before 2013, Group A increased relative to Group B in 2014. We conclude that the Moodle-based system is more effective in reinforcing basic knowledge than the paper-based system.

6 Results of FCI

It was confirmed in the above section that the review test is effective in reinforcing basic knowledge of elementary physics. In particular, the Moodle-based review test is more effective. In this section, result of Force Concept Inventory (FCI) test is summarized. FCI is a test designed to assess student understanding of the Newtonian concepts of force (Hestenes, Wells & Swackhamer, 1992). FCI pretest and posttest was carried out at the beginning and the end of the semester in the class of Physics I. The FCI gain is defined by the same equation as equation 1 in the above section. The results of the gain are summarized in Table 1.

As shown in Table 1, the gain in FCI is positive but small for classes as a whole in the academic years of 2013 and 2014. In 2014, there is no significant difference between Group A and Group B. This result suggests that the review test cannot be expected to improve retention much, though it improves the basic knowledge acquisition.

7 Conclusion

In this study, the effect of the review test on the acquisition and retention of basic knowledge in the elementary physics was investigated on the basis of test data. In section 4, the effect of the review test on the acquisition and retention of basic knowledge is further confirmed by further data from the final test of the semesters. In the section 5, it was found that the introduction of the Moodle-based review test improved the acquisition of basic knowledge more than the paper-based review test. However, the review test cannot be expected to improve effectiveness much about the result of FCI test as discussed in the section 6. From these considerations, further development of education of physics in classrooms needs more improvement in addition to the review test. Active learning is one possibility for improvement -for example, interactive computer based tutorials, or workshop physics (Redish & Steinberg 1999).

In general, the prerequisite for active learning is the background knowledge, because the active learning stimulates deep learning which makes a linkage between different forms of basic knowledge. It can be concluded that acquisition of basic knowledge using the review tests and the active learning are complementary approaches.

Acknowledgment

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GAME-BASED LEARNING IN PHYSICS

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 videos 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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 295–301). 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 modelling 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 videos 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.

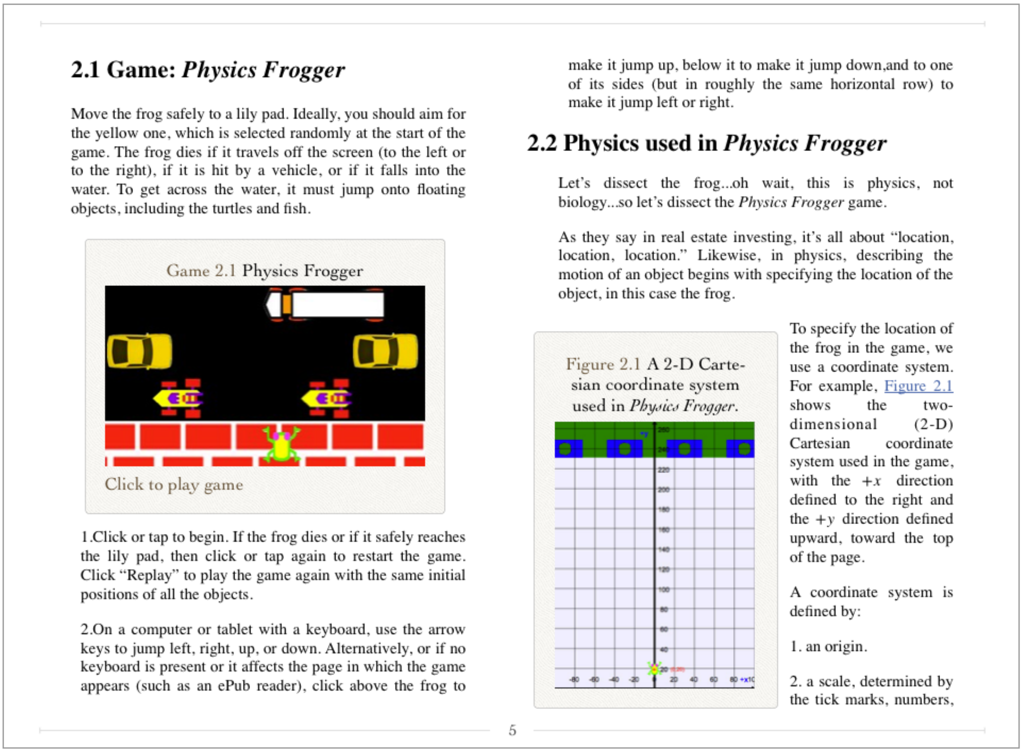
Pursuing these objectives, our design for the eBook is based on the following guiding principles:

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.

Game 2.1 Physics Frogger

Click to play game

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,

5

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

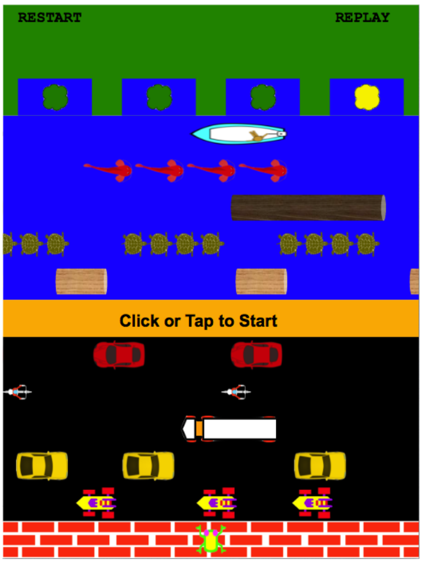


Fig. 2. Game Physics Frogger used for motivating coordinates systems in two dimensions.

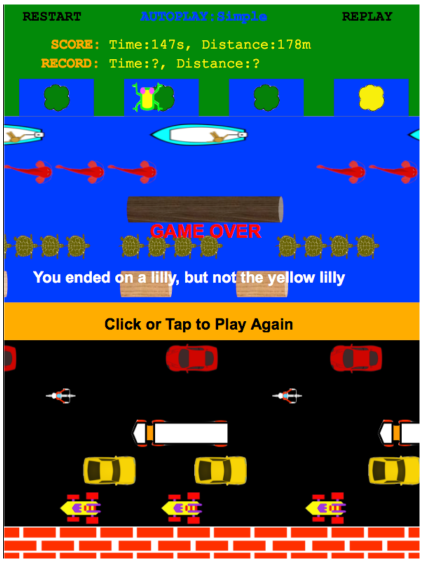


Fig. 3. Game Physics Frogger with chosen final position and scores.

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" (IDFP, 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 taping 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 MathML[1].

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

Ertl, B. (2016). Game-Based Learning for Supporting Self-Confidence and Motivation of Female STEM Students. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 303–311). European Physical Society.

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; Ihsen, 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 Decy and Ryan's (1992) self-determination theory on motivation and try to establish flow (according to Csikszentmihaliy, 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* (Se^{3}N).

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 Se^{3}N. 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

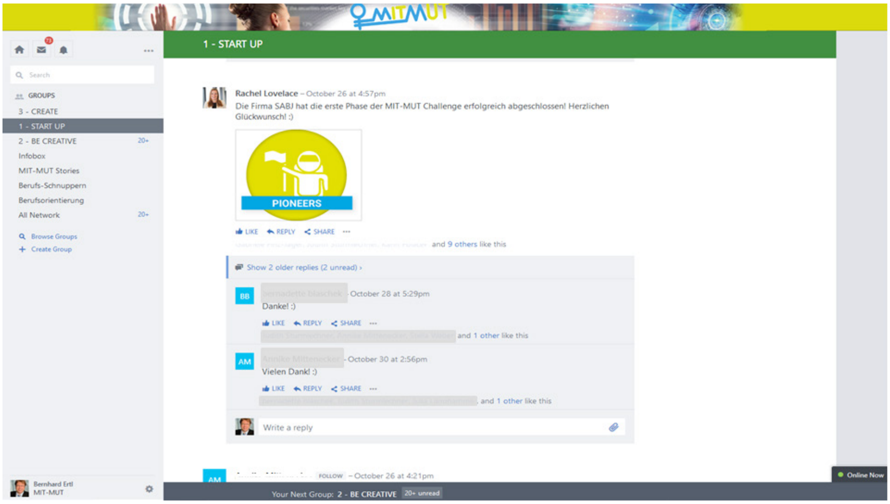

Fig. 1. Screenshot of the Se^{3}N.

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 Se^{3}N. 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 (Se^{3}N)

The Se^{3}N 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 Se^{3}N and

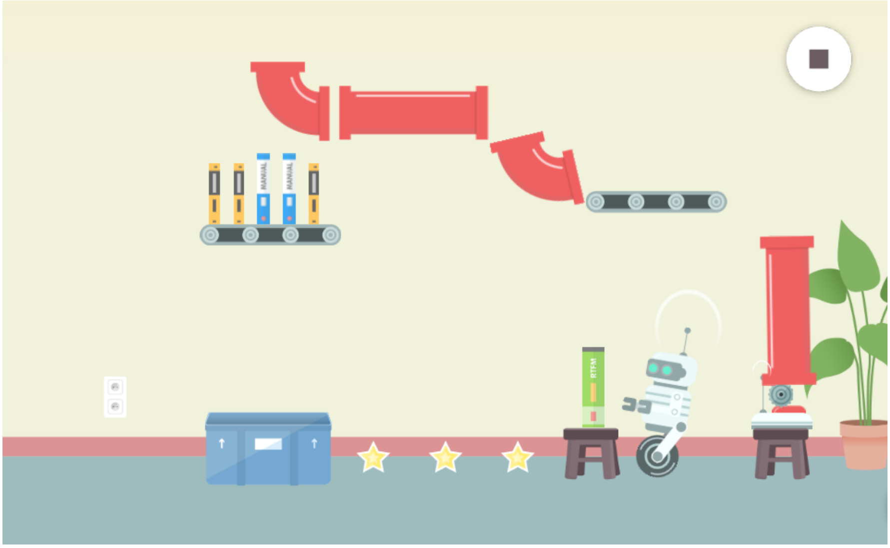

Fig. 2. Screenshot of the physics mini game.

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 Se^{3}N. 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		
		M	*SD*	*M*	*SD*	*n*	*t*	*p*
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 Se^3N 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 parrotted 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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 313–322). 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 CO_2 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 word'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]

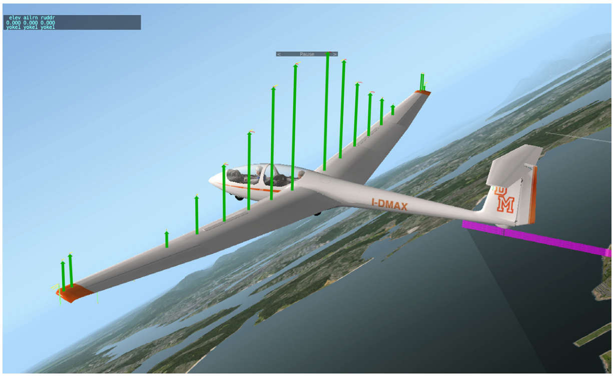

Fig. 1. X-Plane 10 screenshot with one visible flight model (here: forces acting on the wings) and flight path visualization (purple).

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

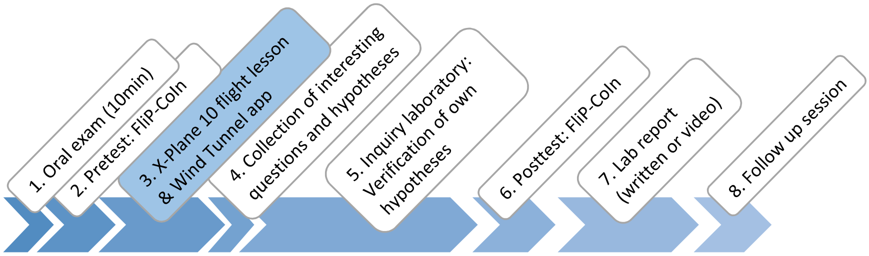

Fig. 2. Roadmap for the laboratory module.

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-CoIn, 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-CoIn post-test. Finally, feedback to the lab reports is provided and the FliP-CoIn 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).

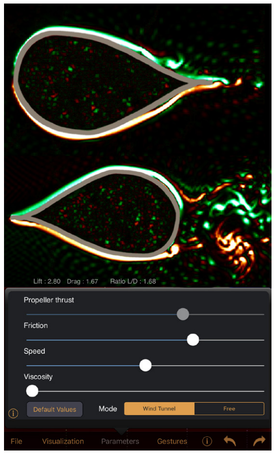

Fig. 4. Screenshot of a 2D wind tunnel app with curl visualization and adjustable parameters.

dynamics is crucial to tackle global 21st century problems. Scientification[2] 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 ZuS[3] 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.

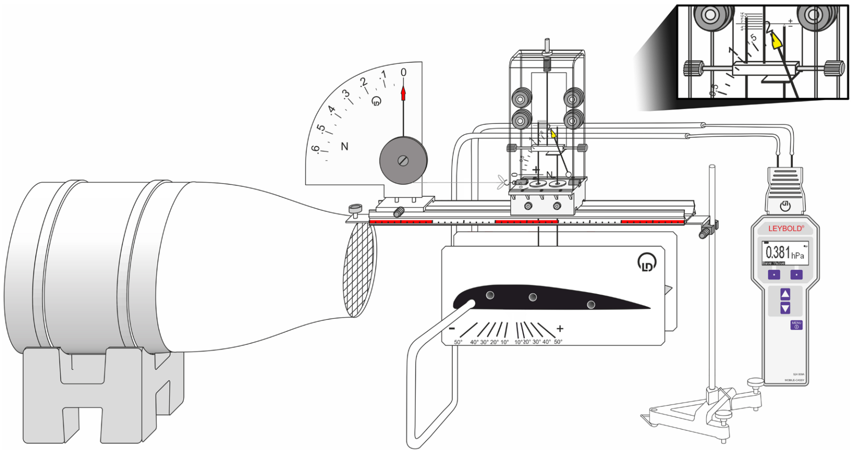

Fig. 5. Modified experimental setup (based on LD Didactic P1.8.6.2), schematically.

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 profiles[5]. 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

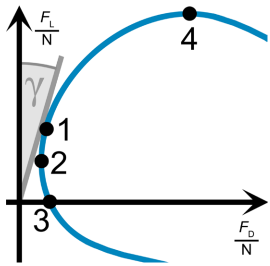

Fig. 6. Airfoil profile drag polar, schematically: best gliding angle γ, point of best gliding (1), lowest drag (2), zero lift (3), maximum lift (4).

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.

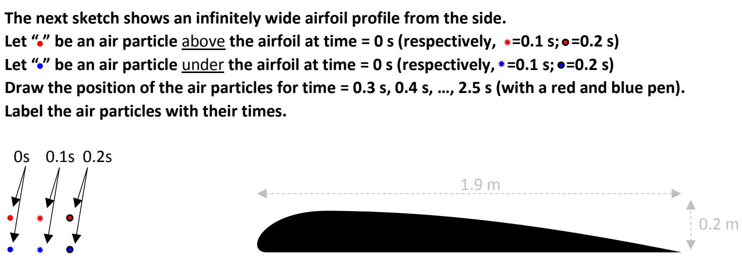

Fig. 7. Example task from the Flight Physics Concept Inventory (FliP-CoIn).

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 frontsides 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 tailing 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.

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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 (2015-12-04)

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

CERN’s Media Lab Games in Upper Secondary Physics Education: Overcoming Baek’s Barriers to Uptake Computer Games in Classrooms

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In recent years, education styles shifted from teacher-centered towards student-centered approaches that foster student-student and student-teacher interaction. A new approach in interactive teaching has been realized through *Game-Based Learning* (GBL). In this paper, we first give a definition of GBL and present a teaching technique for elementary particle physics inspired by the work of the CERN Media Lab in Geneva. An evaluation of the technique was made with special respect to the difficulties of using computer games in classrooms.

1 Introduction

1.1 Game-based learning

Since the beginning of this century, the term „Game-Based Learning“ has been discussed by authors such as James Paul Gee (Gee, 2005), Diana Oblinger (Oblinger, 2006) and Marc Prensky (Prensky, 2001). Sometimes the word „Digital“ is added to highlight that computer and video games are involved (Le, Weber & Ebner, 2013).

GBL is a way to transfer knowledge using a playful introduction to a new topic. In recent decades, *Digital Game-Based Learning (DGBL)* has received greater attention due to the widespread use of computers in upper secondary education. DGBL tries to improve the overall success of learning activities using computer games. An important goal is to develop content knowledge and foster intrinsic motivation at the same time. Both in Game-Based Learning and in Digital Game-Based Learning, the focus is on the “fun” of learning; this is implicit even in the media used to support and guide the process of learning. Consequently, the student should not have the feeling that the game is an academic activity (Pfannstiel, Sänger & Schmidt, 2009).

1.2 Baek’s six Barriers

Young Kyun Baek pointed out six barriers for the introduction of computer games in classrooms (Baek, 2008). First, he highlights the inflexibility of the curriculum. It is difficult to integrate gameplay in lessons since the curriculum must be followed closely and often within a short period of time. Given that, Baek notes the difficulty in finding a motivating educational game that fits seamlessly into existing curricula. Second, Beak lists the negative aspects of gaming—such as addiction to playing, excessive competition in classroom, social isolation, and akinesia. Third, he describes the students´ lack of readiness. Students need time to assimilate the rules and techniques of a new game; moreover, teachers who are not familiar with digital games have similar difficulties. Fourth, Baek addresses the lack of supporting media. Because of this, teachers must prepare lessons on their own. His fifth barrier is the students´ fixed classroom schedules. This is analogous to the inflexible cur-

Westkamp, N., Keller, O., Bresges, A. (2016). CERN’s Media Lab Games in Upper Secondary Physics Education: Overcoming Baek’s Barriers to Uptake Computer Games in Classrooms. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 323–328). European Physical Society.

riculum, but refers to the problems of "45 minute teaching" which is essentially a barrier to set up a rich context for learning. His final barrier is the limited budget of schools. Many existing schools do not have the required budget for computers, games and the necessary high-speed networks.

In order to test GBL as a teaching method without the influence of technical and financial problems, we have developed a non-digital learning game to teach basic concepts of elementary particle physics. This topic has been part of the German curriculum for several years, however, teachers still complain about the lack of appropriate media and teaching strategies.

2 CERN Media Lab

The European Organization for Nuclear Research (CERN) is the world's largest laboratory dedicated to the study of elementary particle physics. One of its mandates, to publish and share new scientific findings within the scientific community and with the general public, is supported by the CERN Media Lab. This team develops specific outreach tools and interactive experiences. The objective is to inform, spark curiosity and engage laymen as well as students in the field of particle physics.

A major project that is being continuously developed and expanded by the CERN Media Lab is the "LHC Interactive Tunnel"[1]. The LHC Interactive Tunnel is an immersive installation where people can create particle collisions by kicking virtual protons like footballs and observe how particles gain mass by observing their whole body in a playful simulation of the Higgs field. Another game explores the "Energy Timeline of Accelerators and Particle Experiments" (ETAPE)[2]. It was developed as a touch screen application for visitors in exhibitions and science centers to rediscover particles along the historical timeline of particle physics using the GBL method. The iPadPix project makes invisible radioactivity visible by augmenting reality on the screen of a tablet device (Keller, 2015). A live video feed of the tablet camera is combined in real-time with an overlay of data from a particle detector that shows different tracks, depending on the particle type and energy. This educational tool enables an intuitive and new way to understand radioactive decay. Weakly emitting objects such as stones (or the natural background) can be examined by moving iPadPix across an area.

3 Designing a teaching concept for elementary particle physics

The following teaching concept tries to integrate the ETAPE game and other GBL tools in order to overcome the barriers outlined by Beak. The teaching concept is a game of its own framing story and levels.

We pursued the goal of creating a complete learning environment, since GBL is a valuable way to motivate today's students to learn. The use of this method is necessary to adapt to the changing culture of today's students (Prensky, 2001). Out of this approach, stress can be reduced and the environment can promote the experience of „flow" (Csikszentmihályi, 1990), a psychological state of seemingly effortless action. Competition is introduced in the game as an essential part of Game-Based Learning. Nevertheless, the build-up of competencies in students is seen as a separate dimension: Only one group can win the game, but everybody can learn from it.

3.1 The sequence of the teaching concept

At the beginning, we establish a context story for game based learning: Students of two high-school classes were randomly divided into competing groups. To create a motivating learning and playing environment, this story that frames every station and promotion opportunity has been created. A competitive element is part of this story: The best scientists

1 http://medialab.web.cern.ch/content/interactive-lhc-tunnel

2 http://medialab.web.cern.ch/content/etape

of the class will have the opportunity to do research at CERN. To find out the best group of scientists, the groups had to solve science problems in a sequence of stations to advance their `career levels' and to do so faster and better than the other teams.

An introductory video immersed the students into the context for learning. In this short video, an actor plays the role of a CERN scientist in an imaginary videoconference and explains the goal of the game. The lesson is divided into five stations. Stations provide tasks the students are required to solve. Each station focuses on one major aspect of elementary particle physics:

1. Introduction to elementary physics.
2. Elementary particles.
3. Exchange particles.
4. Accelerators and detectors.
5. The final station, which involves a card game.

Comparable to a complex model of competencies, students progress through the game in two separate ways: First, there is a level promotion after each completed station. Second, there is the possibility of career advancement for the whole group in the middle of each assignment.

The level promotion symbolizes the progress of the whole group trough the content of the game: Task and assignments are completed, new particles are found etc. The level progression of a group ultimately leads to the end of the game, with one group declared "winning team".

The career advancement, on the other hand, symbolizes the progression of key competencies of each member of the group. Like competence progression in real life, this element of the game is persistent, non-competitive, and sometimes independent from the success of the whole group. If a student demonstrates competence in explaining how a certain particle can be detected, the student earns the expertise of being an "elementary particle physicist". If the student demonstrates competence in explaining how a particle accelerator works, the students earn the expertise of being an "engineer with PhD in Physics". Competencies are demonstrated to the teacher whenever the group feels ready for it; the expertise earned can be helpful to solve the task in the given station. For example, an "engineer with PhD in Physics" receives a compact synopsis of particle physics detectors, where a "student" has to search the internet to find more or less suitable descriptions.

For example, students play with the ETAPE game as part of the second station and solve a crossword puzzle. To solve the puzzle, students need to collect and transfer their knowledge from the ETAPE game. If fewer than five words remain unsolved in the crossword puzzle, and all given answers are correct and can be explained to the teacher, the team can progress from *student* to *elementary particle physicist* status. If the solution word of the entire crossword puzzle is correct, the whole group is automatically promoted a level.

The lack of digital games for elementary particle physics motivated us to use a digital game in the station described above. For the other station, we developed non-digital materials for the students; nevertheless, we still followed the conceptual goal of the GBL method. In fact, the whole lesson represents a game. This game includes many elements of other digital and social games.

3.2 The elementary particle card game

In the final station, the whole team either wins or loses in a card game based around elementary particles. The groups play this game one-to-one. After each round, the winning team ascends one level while the losing team descends one level. It is also possible to play the card game round-based against three or more teams. In that case, after each round the winning team ascends one level and all other groups descend one level. The aim is to reach the research goal: to detect two different elementary particles. To detect these particles, the players must build accelerators. The discovery of particles will lead to more funding, which may be invested in the construction of larger accelerators.

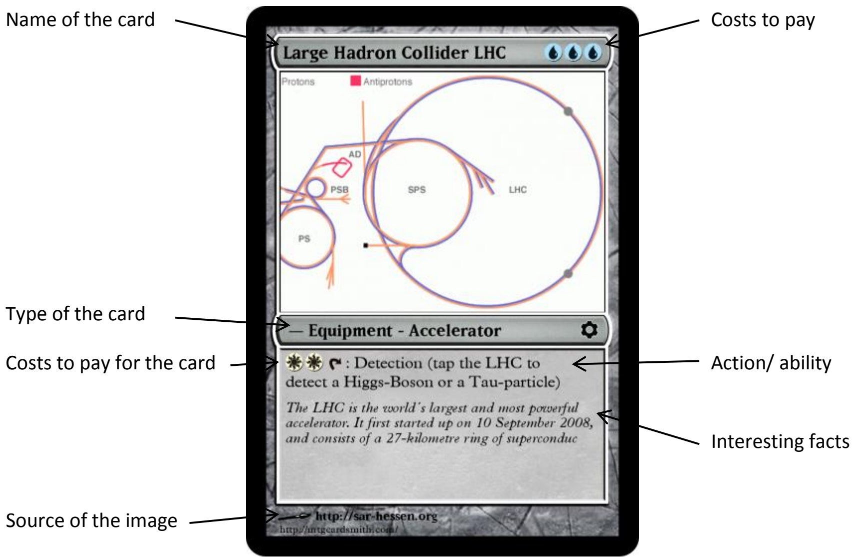

Fig. 1. Description of one card from the card game.[3]

It is also possible to invest the money in research to refute the claim for a particle detection of competing groups. Special events can, for example, lead to the shutdown of an accelerator. The game was developed after a visit to CERN Media Lab and transports the experience of working in an elementary particle physics laboratory in a playful way, including scientific and economic aspects.

Figure 1 shows one of the cards about the LHC at CERN as an example.[3]

Three gaming rules are established in the class prior to the game start:

1. Try to establish a quiet game climate. Don't yell, don't snap at your peers.
2. Maintain a scientific attitude. Use scientific language where possible.
3. Ignoring the rules of the game means your team will be demoted one level

Throughout this GBL approach, we try to create a playful environment that supports teamwork and good social behavior and provides motivating associations with leisure games. Every station provides the opportunity for students to reproduce their knowledge, to reorganize, and to transfer their skills.

4 Evaluation

The lesson was piloted with two classes in a German upper secondary school. To test the effect of Game-Based Learning vs. normal Learning Stations, we used the gaming environment as test group and students of the other class as control group. The control group used the full set of stations, but without the possibilities of winning or losing a game. Each unit lasted 180 minutes, divided into two sessions of 90 minutes in both the test and the control group. The Teachers of the class remained in the classroom to provide classroom management. The instructions on how to play the card game were given by the researchers who developed the game.

3 The cards of the cardgame have been created with *MTG Cardsmith – A Magic: the Gathering Card Creator* (Linode, 2015); URL: http://mtgcardsmith.com/mtg-card-maker

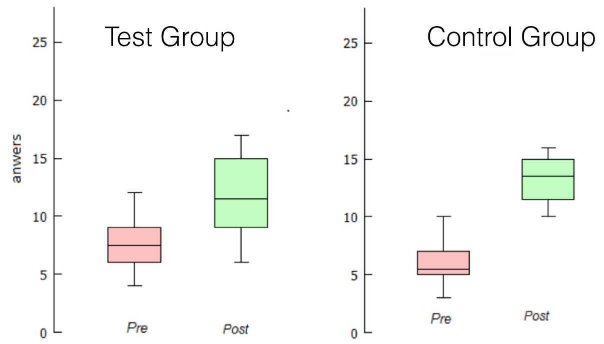

Fig. 2. Boxplots for evaluating the teaching concept.

To evaluate the lessons, a pretest at the beginning of the first session and a posttest at the end of the second session were performed. The classroom teacher observed group behavior and provided feedback after every session.

4.1 Data Source 1: Evaluation of the student feedback

After conducting the lesson, students were asked the questions *„How do you like the lesson? What appeals to you? What should be changed?"* This led to valuable feedback. Answers included:

1. *It was something new and rich in variety.*
2. *I liked it, because it was fun.*
3. *I liked it, because it was different (to usual class). You push oneself more to handle the learning content.*
4. *The card game at the end was quite fun. Sometimes the pressure of time was too great.*
5. *It was a good lesson because the learning took place independently and essential knowledge was built up. However, with more teaching done by the teacher you would be able to learn more.*
6. *I appreciated that considerable effort went into the design and implementation. But I would've wished for easier explanations in some cases.*

4.2 Data Source 2: Pre-posttest with multiple-choice questions

The quantitative pre-posttest provided the following results, which are illustrated with boxplots in figure 2. Figure 2 shows two boxplots pre-post for teaching with the Game-Based Learning environment (left), and two boxplots pre-post for teaching without the GBL environment (right.).

While the differences between the median values of test and control group are marginal, a larger distribution in the posttest of the group that was part of the GBL environment is obvious.

4.3 Data source 3: Partaking Observation by in-classroom teachers

The observing teacher noted that the GBL teaching concept has to be redesigned to take more workload away from the teacher. In the first two lessons, teacher workload was high due to the large number of student questions combined with the task of checking the successes of five different groups. Consequently, the teacher of the test group with the GBL environment settled with evaluating the progress of each group only after the completion of each station. Additionally, more explanation was given in advance. The students worked intensively because of the competition, and they also worked faster. For example in the fourth station (on the topic of accelerators and detectors) the students inside the gaming environment gave their response in a maximum of five minutes. The students without the gaming environment needed up to 20 minutes for the same result.

5 Conclusion and remarks with respect to Beak's barriers

The example demonstrates how Baek's barrier of "inflexibility in the curriculum" can be avoided. The digital games were used to complement learning stations, and the topic of the learning stations has been chosen according to state curriculum. Interestingly, students' lack of readiness has not been observed during Game-Based Learning. On the contrary, the students enjoyed the lessons and integrated themselves actively in the gaming environment. Teamwork and alternating tasks at every station dominated, negative effects such as social isolation, akinesia and addiction were not observed. It was observed that the preparation time for DGBL and GBL was comparable to a normal school lesson. The final barrier to GBL implementation described by Baek, the limited budget of schools, is less relevant today, since and a large number of educational games are freely available. According to a german study (JIM 2015), 92% of german students in the age group 12-19 have access to a smartphone that can be used for Digital Game-Based Learning.

The learning gains of Game-Based Learning are roughly comparable to station learning, but the particular example of Game-Based learning demonstrated a high demand of classroom management and structure. Qualitative data from part-taking observation and feedback from students (e.g. answer 6) suggest that the distribution of learning gains in the test group can be partially explained with difficulties to clearly communicate the rules of the game to every student, resulting in a high cognitive load for some students to follow the game progress.

For Non-Digital Game-Based Learning, the cost of printed cards and supporting media can be burdening, so a Digital Game-Based Learning is favorable when smartphones or tablets are available in the classroom. Electronic tracking of students's score and progress may effectively reduce teachers's workload.

Based on our experience, we would suggest to reserve additional time for explanation and teacher instruction. The qualitative evaluation shows good acceptance and motivational effects. The quantitative evaluation failed to provide evidence for better learning gain in the test group, compared to station learning. A repetition of the study should faciliate larger groups, more explanation prior to the gaming, and should evaluate more sessions. Here, a conversion of the paper-based game into a digital game-based learning version seems mandatory to provide a stable and reliable classroom situation for educational research. Educational hands-on devices like iPadPix from the CERN Media Lab, which encourage playful learning, could be used to demonstrate the usage of particle detectors in the corresponding station.

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CONCEPTS TO INITIALIZE LEARNING ACTIVITIES WITH MODERN MEDIA

Integrated Use of Scratch and EJsS 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 EJsS 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 countries[1] 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 are expected to learn how computers and computer systems work, to design and build

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

Sapia, P., Bozzo, G., & Guerriero, R. (2016). Integrated Use of Scratch and EJsS for Promoting Coding Skills of Prospective Primary Teachers. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 331–340). European Physical Society.

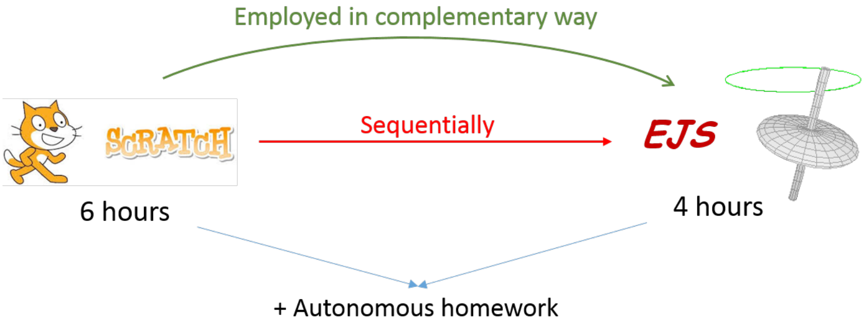

Fig. 1. Structure of the learning sequence tested: two pieces of authoring software, Scratch and EJS, were sequentially employed in a 10+20 hour (in class + at home) activity. The two authoring tools were used in a complementary way, allowing learners (novices in coding) to shift from a visual block-based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

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 – EJsS – (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. In particular, the feasibility and the learning value of the lessons is qualitatively evaluated

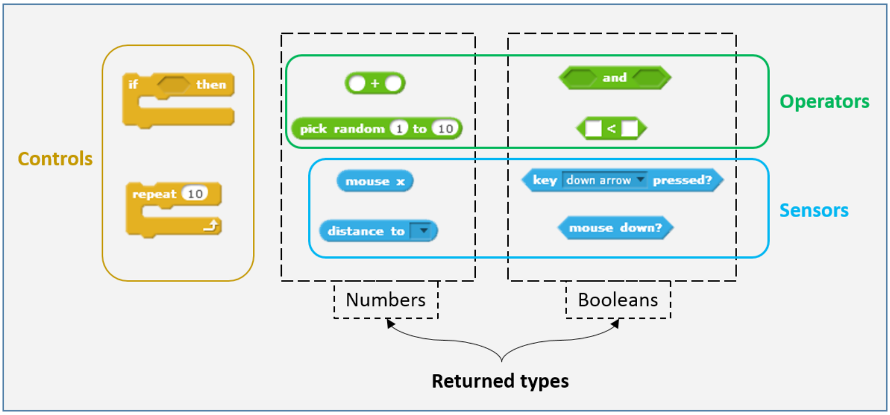

Fig. 2. The function and typology of Scratch's blocks are visually coded by their shapes and colors. For example, Operator blocks are Green, while Sensor blocks are Cyan. For both categories, blocks are shaped according to the types of values they return: the members that output Numbers are oval-shaped, 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 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 EJsS, 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 start their programming experience by simply playing with the bricks and exploring dif-

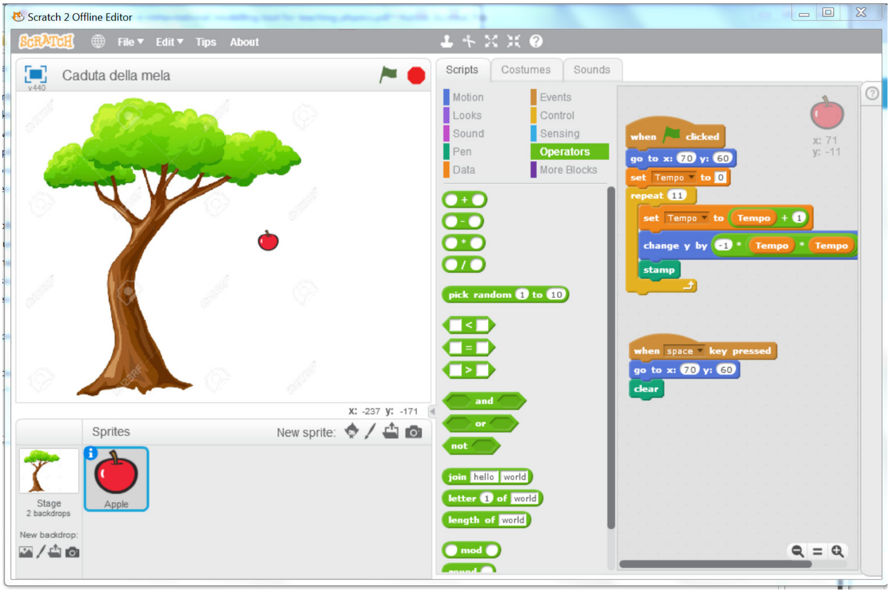

Fig. 3. Structure of Scratch's window. Four main panes are present: i) The main pane (upper left, containing the tree in this figure), is the stage where the animation is shown; ii) The command palette (center of the figure), with tabs and buttons to select categories of available command-blocks; iii) 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.

ferent 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 scripts[2] 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; LearnScratch, 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).

a)

b)

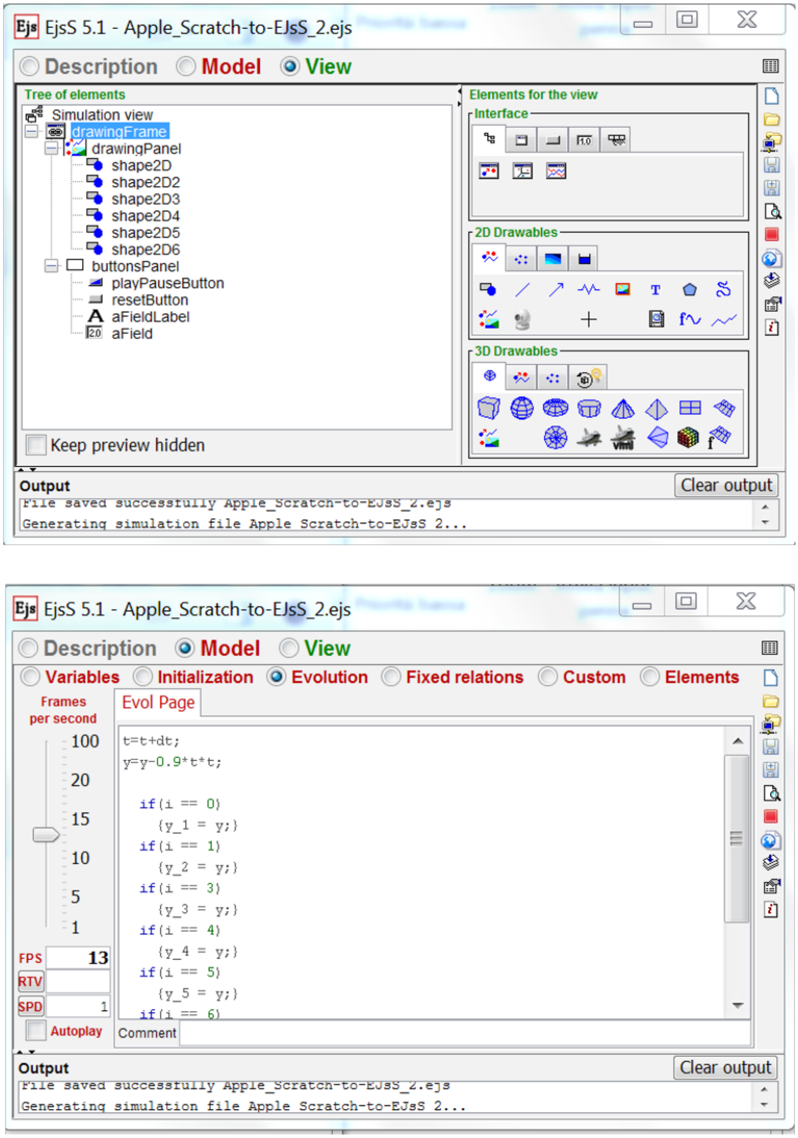

Fig. 4. EJS workspace features three visualization modes, inspired by the Model-Control-View design paradigm. The Figure shows the modes that are used in the proposed learning sequence: The View mode (a) allowing users to build graphical interfaces, and the Model mode (b) that permits customized textual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

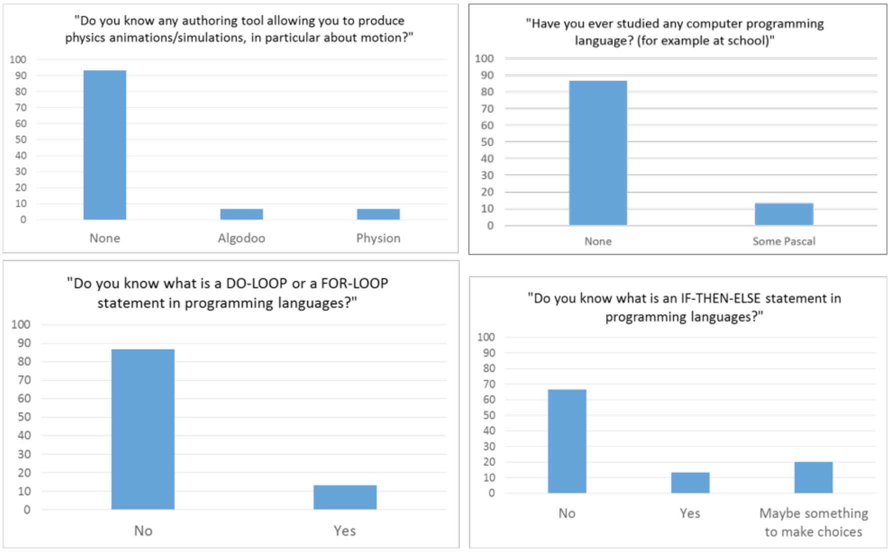

Fig. 5. Taxonomy of students' answers to some typical questions in the pre-test. These results show that students have no prior knowledge of programming languages and little experience with multimedia tools.

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". EJsS 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 EJsS plays a somewhat similar role to the Script pane of Scratch[3] (Figure 3).

2.2 Rationale of the proposal

Our learning sequence on coding has been inspired by a special feature of EJsS, not present in Scratch. While the latter is a purely visual programming environment, EJsS 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 EJsS. In other words, after having implemented a simulation in Scratch, learners can use the visual capabilities of the EJsS 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!

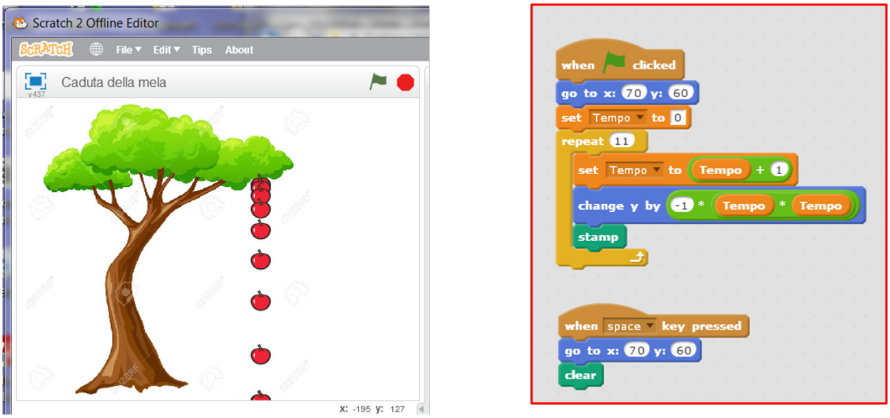

Fig. 6. An example simulation made by students: the fall of an apple from the tree. The left portion of the figure shows the appearance of Scratch's stage after the execution of the apple's script, which is shown on the right.

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 EJsS. To this end, students used the visual building capabilities of the EJsS'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 EJsS'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 EJsS. With this goal, the students translated the "repeat" visual loop of Scratch (Figure 7, top left) into a portion of code (in the EJsS

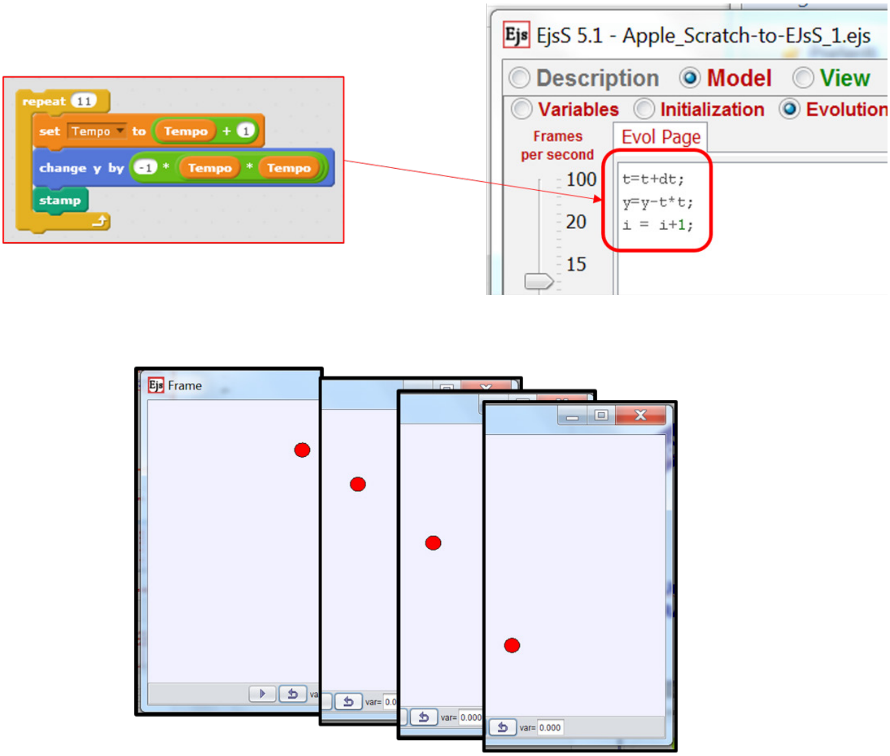

Fig. 7. An example translation of Scratch's visual code (top left) into EJS's textual script (top right), leading to incorrect behavior of the scripted object, the apple (the not-persisting red circle in the bottom portion of the figure).

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.

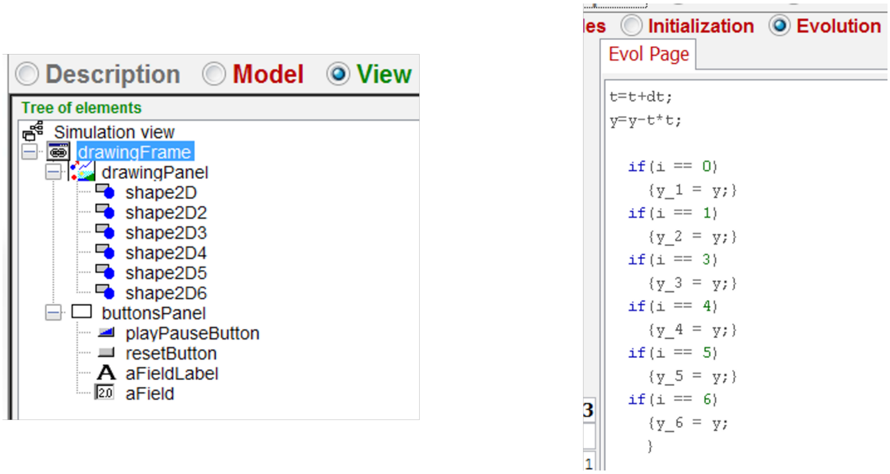

Fig. 8. The coding solution given by learners to the non-persistence problem of the falling apple shown in Figure 7. Many instances of the same shape representing the apple have been introduced (in the View pane, left) governing their behavior with an appropriate script in the Evolution pane (right).

3 Conclusions

In this work, we described the synergetic introduction of two very different authoring tools, "EJsS" 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 EJsS. 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 EJsS. 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 EJsS) 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 (Dammaschke & 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).

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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.

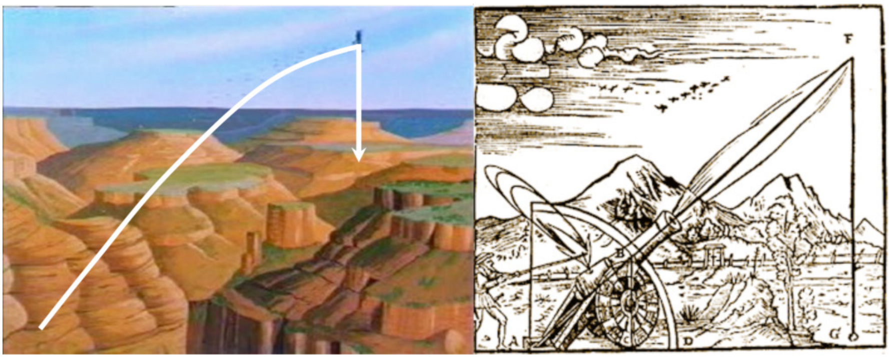

Fig. 2. Wile E. Coyote (Wile E. Coyote and The Road Runner) and the Impetus of the cannonball (Impetus).

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 Ambrosis, A. (2016). Home Made Spectrophotometer for a Laboratory Bridging Optics and Modern Physics. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 347–355). European Physical Society.

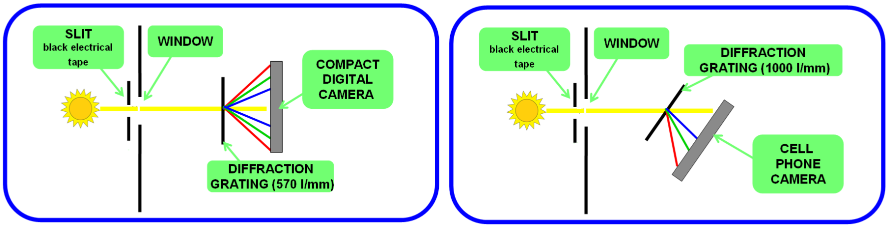

Fig. 1. The spectrometers set up: parallelepiped cardboard box with a hole for the lens of the camera on one side and a narrow window made affecting the cardboard with a cutter on the other side. Two pieces of black electrical tape are placed over the window to form a collimating slit. The light source 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.

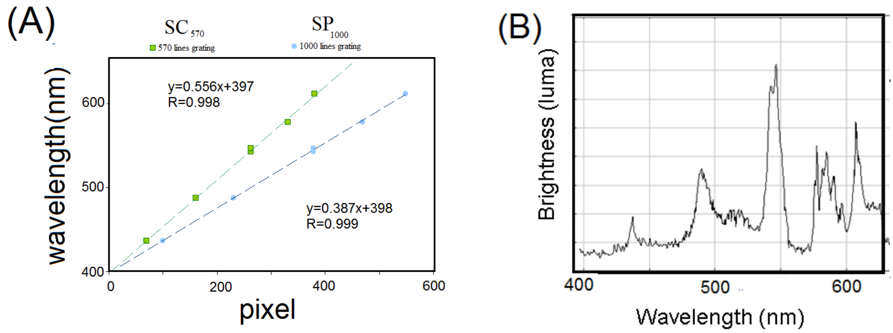

Fig. 2. (A) The wavelength–pixel calibration curves of the spectrometers, based on the fluorescent lamp spectrum. Brightness versus pixel plot is provided by Tracker.

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.

$$Y_{luma} = 0.2126\,R + 0.7152\,G + 0.0722\,B \tag{1}$$

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:

$$Y_{measured} = 0.2126\,R^{\gamma} + 0.7152\,G^{\gamma} + 0.0722\,B^{\gamma} \tag{2}$$

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 ($I(\lambda)=Y(\lambda)/R(\lambda)$).

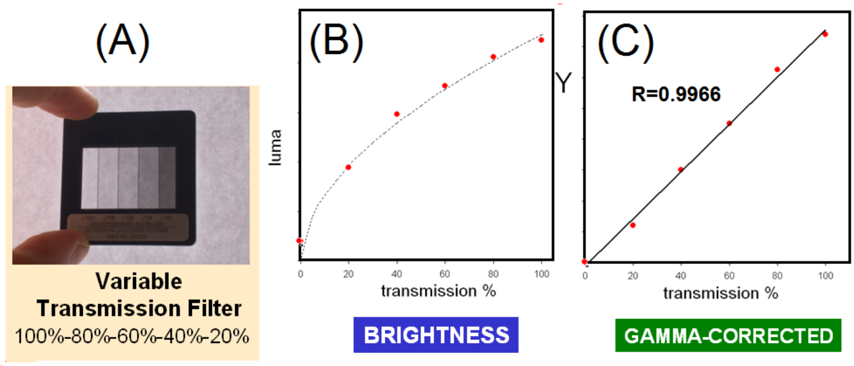

Fig. 3. (A) Jpeg image of light passing through the variable transmission filter. (B) Brightness versus transmission as measured according to eq. (1). (C) Luminance measured using gamma correction.

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:

$$h/e = V_F \lambda / c \qquad (3)$$

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 ($4.1 \cdot 10^{-15}$ eV·s) to within 7%, or $3.9 \cdot 10^{-15}$ eV·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.

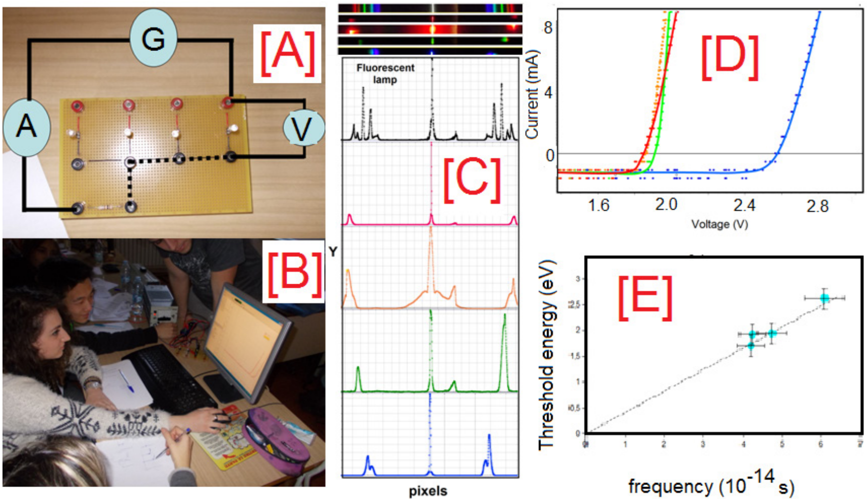

Fig. 4. [A] The basic circuit employed to carry out *I–V* LED characteristics makes use of 4 LEDs, with an external nominal load resistor of 100 Ω to prevent too high currents, a standard low-voltage power supply and a current-voltage sensor by PASCO. [B] Students at work in the Lab. [C] Spectra for 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±0.004×10^7 m^{-1} with an error difference less than 0.06% compared to the accepted value of 1.097 373 × 10^7 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.

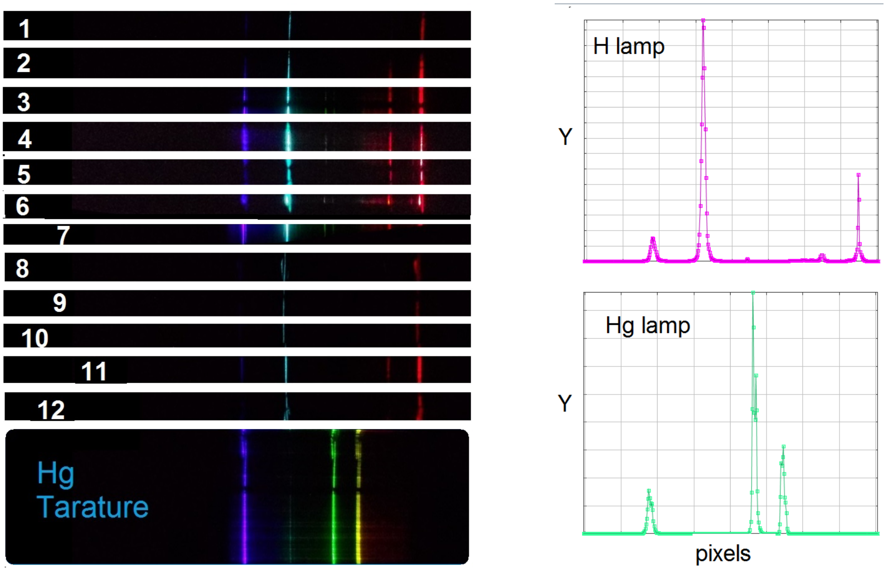

Fig. 5. (A) Spectral lines (red, cyan, and blue) clearly visible in the photos. The spectra are compared with the one of the fluorescent lamps used for calibration. (B) Graphs Y vs. pxl for one of the 12 trials, obtained with Tracker compared with the Hg spectrum.

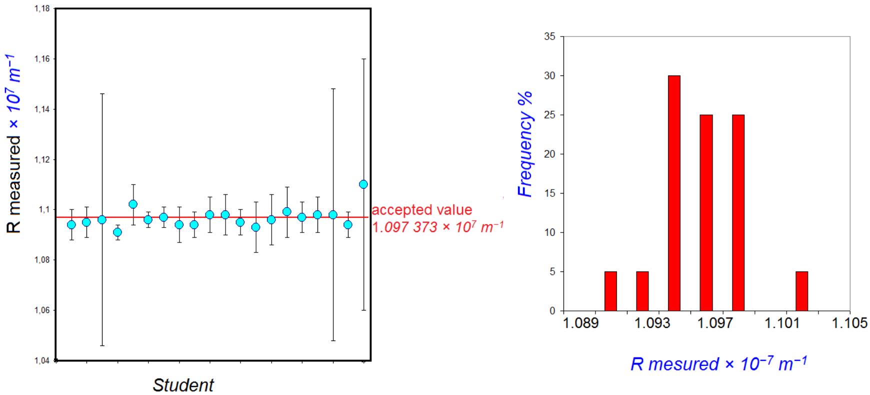

Fig. 6. Values of the Rydberg constant measured by students with the error bars and measurements distribution.

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.

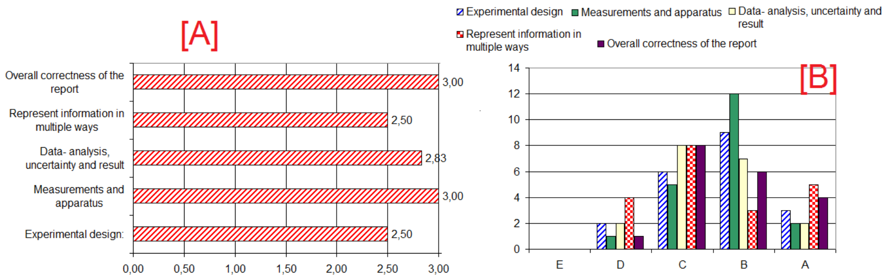

Fig. 7. The average result on each item and the students' distribution in each level.

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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The Impact of ICT and Multimedia Used to Flip the Classroom (Physics Lectures) via Smart Phones and Tablets

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Based on the conclusions of my previous research, it has become clear that natural sciences education is in crisis around the world (OECD, 2000, 2001, 2005). Physics lectures need to be made more attractive and interesting. Unfortunately students are not really involved in hands-on experiments, because the infrastructure of schools and university laboratories differ greatly (Jarosievitz, 2011).
If we want our students to leave universities, colleges or even secondary schools with an adequate knowledge-base and applicable skills in physics, we need to take advantage of ICT, multimedia (text, pictures, animation, sound, video and interactivity) and new devices along with their applications (Jarosievitz 2011, 2009). All of these new possibilities require a well-constructed hypothesis for meaningful use which is also researched here along with new educational methods. In order to use the new methods and tools, I have formulated the goal of the activity. During implementation, all activities should be controlled by the teacher and the cooperation method should be combined with the ICT and Multimedia (Vaughan, 2011). We believe that the use of these resources in physics lectures will strengthen the positive impact, and change the students' attitude.

1 Introduction

Globalization and technological advancement have accelerated enormously in recent years; accordingly, the use of Information Communication Technology (ICT) in education has become a common requirement (Punie et all, 2006). ICT is a diverse set of technological tools and resources used to communicate, as well as to create, disseminate, store, and manage information electronically. This can be done via computers, Internet, broadcasting technologies (radio and television), or telephones. The effective integration of ICT into the educational system is a complex process that involves curriculum and pedagogy, institutional readiness, teacher skills, and long-term financing, among other factors.

The effective use of Information and Communication Technology (ICT) in Hungarian secondary schools began in 1998 when the majority of schools were connected to the internet. The idea to connect the schools – the first Hungarian Schoolnet project – was announced in 1996.

In 2013, a new national report on ICT in Education was published on Insight from the EMINENT Conference 2013 (Insight, 2013). The report led to the following results:

"The Digital Renewal Action Plan 2010-2014 provides the guidelines for the strategy of the Hungarian government. The action plan includes 83 specific recommendations within four action plans:

1. Ensuring equal opportunities for citizens;
2. Increasing the competitiveness of enterprises;

Jarosievitz, B. (2016). The Impact of ICT and Multimedia Used to Flip the Classroom (Physics Lectures) via Smart Phones and Tablets. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 357–363). European Physical Society.

3. The introduction of modern ICT measures in public administration;
4. The improvement of the ICT infrastructure in the country.

The report's plan is in line with the recommendations and goals of the Europe 2020 Digital Renewal Action Plan strategy, and reflected the input of several hundreds of opinions and contributions via a "Digital Consultation" (EUN, 2013) process.

During my educational career I also became convinced that it is impossible to adequately teach some parts of physics without the use of computers or video files and simulation programs —for example, Chain reactions (Jarosievitz, 2006), or exponential decay laws (Jarosievitz, 2015), among other related natural sciences. There are even some universities that do not have enough equipment to show real experiments, let alone secondary schools. In the latter case, the problem is exacerbated by the fact that students often cannot be divided into small groups for laboratory work due to a lack of rooms and incompatible time slots. There may be several subjects in which the use of ICT can aid STEM teachers seeking to refresh their lectures.

There is a widespread view that computers are not necessary if good teachers are available. Others fear that teachers will no longer instruct if they begin using computers. These objections are understandable, but it can no longer be denied: computers are essential to even moderate levels of instruction in the world (OECD, 2000, 2001, 2003, 2004). We also see that many universities already run accredited Massive Open Online Courses (MOOC) instead of bringing students to lectures.

The benefits of computer simulation programs must not be misinterpreted to mean that a computer can be the sole provider of instruction for students of physics and natural sciences! Nothing can replace the experience and the personality of a good physics teacher.

However, interactive, multimedia-based computer simulation programs offer a unique opportunity for students to experiment and work with systems and materials that they would rarely, if ever, be able to actually work with in practice.

Dangerous substances and situations, expensive equipment, and theoretical - even fantastical - ideas can be explored in a way that is more thorough than practical teaching has ever been able to do before. Never before has there been a situation in which the creative mind could be so safely and precisely indulged in these important areas of education. Well-written simulation programs help students to understand better the phenomena or physics laws.

Another advantage of simulations is that students, who are slower or faster, have the benefit of working on less advanced or more challenging experiments, regardless of the pace of the class. This is particularly helpful for students who need to practice material that the class has already covered. Slower learners can continue to explore previous experiments without needing the classroom instruction to be repeated again and again. These students can then replicate experiments until they actually see the correct results. Conversely, advanced learners have the freedom to experiment on subjects that may not be understood by the majority of the class yet. In both cases the slower, and the faster students of a class benefit from combining the power of the computer with the wisdom of the teacher.

We are confident that the role of the teachers and students should be changed. Students should be involved in the lectures, and the peer instruction method should also be very helpful (Mazur, 1997).

Using new learning methods students are kept active by the teachers and will think and learn during the courses, together with the teacher's explanation. Everybody from the audience will leave the lecture room with some impressions about the topic heard on the lecture, and start processing their thoughts afterwards. With the traditional frontal lecture transmission method, students often leave the room with no impact and no idea about what was going on during the course —sometimes they do not even remember the topic discussed in the lecture.

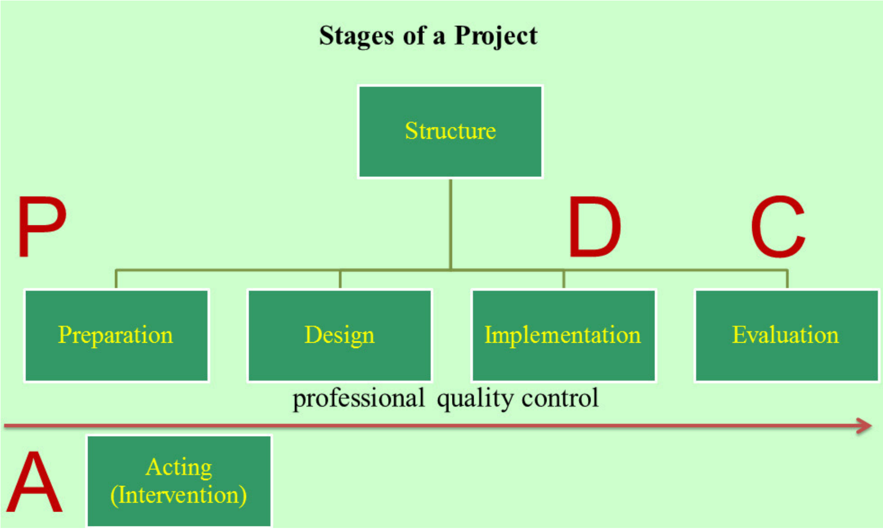


Fig. 1. Stages of the project.

2 Formulated hypothesis

Before testing the new learning methods presented in this paper, I formulated the following hypotheses based on many of the previously published articles:

Using the new methods I expect to:

- improve the memory of students,
- improve their understanding,
- create interactive lectures,
- make the lessons more enjoyable (Jarosievitz, 2005)
- flip the class, „lecture room",
- improve concentration of the students,
- increase my students' interest,
- motivate students for coming evaluations.

3 Flipped classroom implementation

Considering different possibilities and methods the implementation of the flipped classroom I have done using the project method (fig. 1).

In the beginning of the implementation I have created a project plan based by constructivism: a theory based on observation and scientific study. I initially defined the stages of the project.

3.1 Preparation

In the preparation part I determined my first aim: to create a Sharable Content Object Reference Model (SCORM) eLearning (Henson Gawliu Jr, 2012) online training material for my students.

Why do I used SCORM?

The main benefit of SCORM is that the content can be created in an eLearning authoring tool, using tools like Articulate, Captivate, Camtasia etc., and then published by the tool in a SCORM conformant way. Finally the content can be uploaded into any SCORM-compliant Learning Management System (LMS) and then delivered out to learners.

The topic of the content in my case was Electricity, a 5 credit course I taught for BSC students.

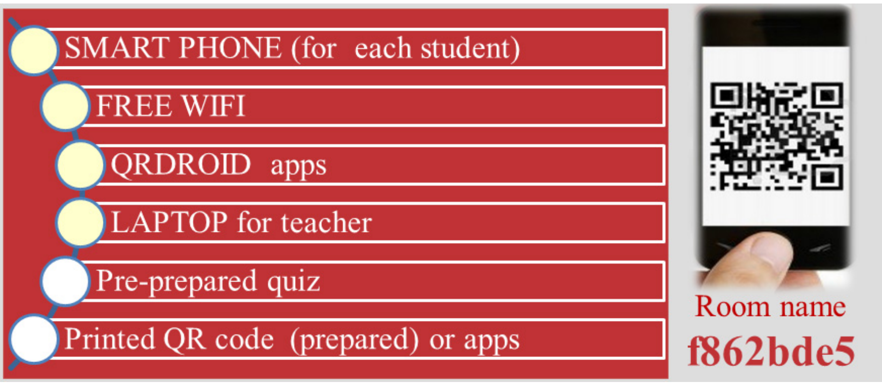


Fig. 2. Requirements.

3.2 Design

In the second stage of the project, the design part, I created the planned content, which contained 1029 slides. This SCORM content I have prepared with Adobe Captivate authoring tool, and finally the package was uploaded to Dennis Gabor College server.

This Electricity course could be seen only by students enrolled to the lecture using intranet, ILIAS (one of the first Learning Management Systems to be used in universities), (ILIAS, 2016).

My online course has 4 major chapters and many subchapters with self-made videos (26) presenting different electricity experiments. Students have access to all materials in advance, and they can watch the videos before the lectures.

In this course students have some quiz questions after each chapters, which they can use for self-evaluation.

In this SCORM content I also created 150 physics exercises with formulas and derivations. Students can prepare themselves and do a lot of exercises before the courses.

3.3 Implementation

The idea to implement a flipped classroom came from a video interview watched by students taught by professor Mazur (Julie, 2012).

The video shows that involving the students actively occurs by the use of cooperative method: pairs of students or groups of students have a voting system in their hands allowing them to express their opinion on a topic or on a question of the professor. Students watch the question, start to discuss (cooperate) and use the voting tool, vote, and see online the anonym answers.

This way students, are well-motivated, since they have to think first, then communicate, cooperate, and be involved in the lecture.

Analyzing the video, and reading several papers I decided to start a research year and implement this method in my Electricity course.

The novum of my implementation consists in the following:

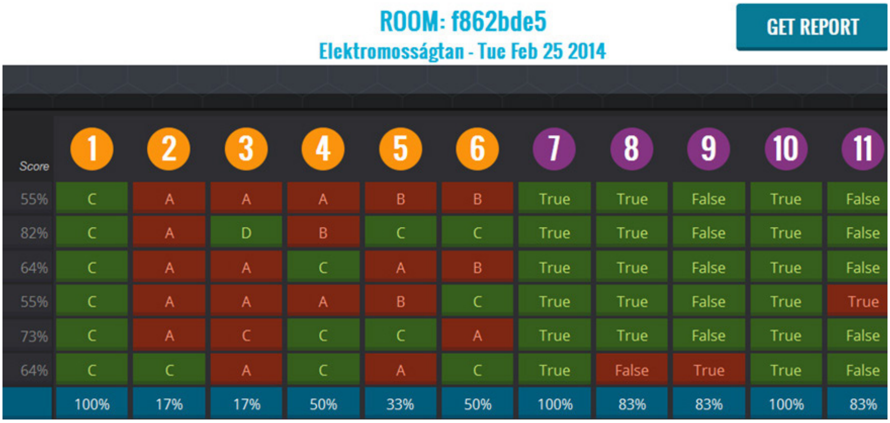
Since we do not have a commercial voting system in the college, I choose a different solution: students used their own devices (smart phones, tablets or laptops) for voting.

I have created all questions in advance, using free online programs. During my lecture the results of the students' vote were also shown online.

I used the flipped classroom method in two different ways during my course:

Firstly I used the prepared questions related to one topic after teaching the full chapter. In this case students have to vote, answering the questions for the whole chapter

I was curious if students understand the material, or I still need to give extra explication of the topic.



ROOM: f862bde5

Elektromosságtan - Tue Feb 25 2014

GET REPORT

Score	1	2	3	4	5	6	7	8	9	10	11
55%	C	A	A	A	B	B	True	True	False	True	False
82%	C	A	D	B	C	C	True	True	False	True	False
64%	C	A	A	C	A	B	True	True	False	True	False
55%	C	A	A	A	B	C	True	True	False	True	True
73%	C	A	C	C	C	A	True	True	False	True	False
64%	C	C	A	C	A	C	True	False	True	True	False
	100%	17%	17%	50%	33%	50%	100%	83%	83%	100%	83%

Fig. 3. Correct and incorrect answers that students provided to the questions.

On the other hand I used the flipped classroom method when I started to explain a new topic or chapter, to my students.

I used Padlet (https://padlet.com/my/dashboard), when I was curious if students turning to each–others could give good suggestion about a phenomena, and I also wanted to know if they were able to use brainstorming together.

During my course I used the following free online programs: http://www.socrative.com/; https://padlet.com/my/dashboard; https://quizlet.com/.

In both cases, student had access to my previously prepared online SCORM course before my lectures – as mentioned earlier. Some of the students who do not have any devices, they turned to their neighbor's and discuss the topics, before they click and answered the questions.

3.4 Some details of the "Use of the voting system" with own devices

Step 1

First I have created a teacher account, and I have created the quizzes online.

Step 2

As a second step I have prepared QR codes for the students, give them also the URL of the site used: https://b.socrative.com/login/student/, and give them the room number. This code I have given to my students in a paper format, which looks like a name card.

Step 3

Firstly students had to scan the QR code that was provided —thus, they needed to have a free app installed to read the QR code, and they also needed an internet connection).

The free app, called: QRDROID program can be downloaded from Google Play.

See summarized the requirements of the "Use of the voting system" (fig.2).

Students used their own devices —usually their smart phones or tablets. During the lecture they followed my instructions and really turned to their neighbor's to discuss the topic based on the quiz questions provided, before answering them.

3.5 Evaluation

Using the quiz questions I evaluated the students using two methods. Sometimes I asked the students to give anonymous answers, other times I asked them to give their names. Since I wanted to assess the effectiveness of the method and not the individual performance of the students, the answering with names, or without was not important for the assessment, but it was important only for different aspects of my research activity. I think that the students took the test more seriously when they had to include their names (fig. 3).

In fig. 3 a screenshot of the online interface is provided. This figure has been projected online during my course.

This table is just one of the examples from the vote, represents the correct and incorrect answers that students provided to my questions. The advantage of this online representation is that I can immediately find out which part of the material was too hard for the students, and where I should spend more time giving explanations. They also can conclude how well they understood my explanation, the physics phenomenon, or the experiment.

3.6 Feed-back

From anonymous personal interviews with my students I can conclude that my students like the peer instruction and innovative teaching method very much, and that they feel it is very useful and that it motivates them more to attend lectures. They also like very much the idea of bringing and using their own devices to lectures. They feel that they are better prepared, and they are more active learners during the lectures, not only passive listeners.

Using the "flip the classroom" method has more advantages: students became more active and motivated to read, and to watch the video given in the e-learning material before my lecture.

I also observed a few disadvantages of the method, however: first, adaptation of this method requires more preparation work by the lecturer. Second, if only a few students are enrolled in the course no comparison can be made for the test group, since no control group can be formed.

Finally, this online SCORM course was prepared in Hungarian, since that is the teaching language in our university. This means that unfortunately, the course cannot be compared to other similar courses used in other countries.

3.7 Acting

I think that in the future, a major goal will be to further increase the motivation of students to join the course, to study in advance, and to join the flipped classroom to increase its impact.

4 Conclusion

I presented some results of my research work using ICT and multimedia and the flip classroom method in Electricity. My results show that this combined method has significant impact and contributes toward:

- modernizing teaching,
- increasing students' motivation and interest,
- catching up with the mobile revolution,
- using mobiles effectively,
- following different high-tech developments.
- Finally I think that using the new methods I was able to
  - improve the memory of students,
  - improve their understanding,
  - make the lessons more enjoyable (Jarosievitz, 2005)
  - flip the class, „lecture room",
  - improve concentration of the students,
  - increase my students' interest,
  - motivate students for coming evaluations
  - create interactive lectures.

I am confident that the formulated hypotheses have been verified and tested. The impact of ICT and multimedia used to flip the classroom (Physics lectures) via Smart phones and tablets could be seen analyzing the student's marks getting on the examination period. Using the flip the classroom method, student's got better mark, and they were attending the courses much more motivated.

It also became clear that if we use only the same old strategies, methods and techniques we will never engage our students, nor will we motivate them or change their attitudes. This method shifts the role of the teacher, and increases audience engagement.

„The future cannot be predicted, but the future should be invented". (Dennis Gabor)

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Concepts to Initialize Learning Activities With Modern Media

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Modern Media (MM), understood as all types of diversified information and communication technologies (D-ICT), is seen as a powerful and attractive collection of tools and methods that enrich the educational resources of scientists and teachers. D-ICT are intended to reach a large and diverse audience via specific media which involves different channels of influence and points to different ways of perception. This paper presents a theoretical basis to categorize proposals and concepts discussed during the MPTL'20 conference seminar with the same title. Some further issues are identified and additional proposals are formulated based on Substitution Augmentation Modification Redefinition Model (SAMR).

1 Introduction

A number of proposals strongly connected with MM in teaching and learning processes has been presented during the seminar held to initiate learning activities as well as during others activities carried out as a part of MPTL'20 Conference. In general, these proposals have tackled the various aspects of D-ICT that fall into five categories of mass communication (Thompson 1995). After small redefinition proposed by the authors, these categories are as follows:

- Comprise technical and institutional methods of production and distribution (from individual initiatives to international projects and from papers to mobile applets).
- Involve the commodification of symbolic forms, as the production of materials relies on its ability to manufacture and distribute (as well as sell) large quantities of the institutional work (for example, science centres and universities rely on their workers and scientific equipment).
- Separate contexts between the production (researching and discovering) and reception (sharing and spreading) of information.
- Reach those 'far removed' in time and space, from the producers (making use of variety of communication platforms).
- Distribute information - a 'one to many' form of communication, whereby products are mass-produced and disseminated to a wide audience (via institutional and social networks).

The above characteristics will be discussed in detail in the following paragraphs and illustrated with examples presented during the entire MPTL'20 Conference.

2 Characteristics of D-ICT

Making physics teacher workshops more abundant is accomplished by significant growth in the number of resource tools and methods arising from D-ICT. These tools include innumerable computers, tablets and phones applications, different modeling and simulation-oriented programs, diversified methods of video analysis and various approaches to computer aided experiment. Such a situation is, on one hand, very inspiring for educa-

Greczyło, T., & Dębowska, E. (2016). Concepts to Initialize Learning Activities With Modern Media. In L.-J. Thoms & R. Girwidz (Eds.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 365–368). European Physical Society.

tors but, on the other hand, may cause discomfort and lead to inappropriate and often perfunctory use of D-ICT. To reduce these harmful effects it is useful to structure MM by looking at their mass media characteristics and allocate them in the contexts of Substitution Augmentation Modification Redefinition Model – SAMR (Puentedura 2014).

2.1 Comprise

MM comprise technical and institutional methods of production and distribution of physics educational materials. It can be seen that new technologies designed for mass media are immediately used for educational purposes. As a medium for sharing ideas - to show and develop proposals for physics education - all available channels from paper to mobile applets are used. A group of physicists associated with the MPTL has performed (since 1996) the MM reviews resulting in the recommendation of D-ICT materials useful in preparation of activities devoted to different subject areas in physics (Debowska 2013).

2.2 Involve

Institutions responsible for teacher training and development of educational materials undertake different actions to bring certain aspects of physics to the broader public. This process often involves the commodification of symbolic forms and extensive use of D-ICT. The production of materials relies on institutional ability to manufacture and distribute large quantities of the outcomes of institutional work. The key examples of such actions are activities of science centres which rely on their workers and scientific equipment to spread physics-related information and concepts. Thus, one can find great collections of good quality teaching materials involving use of D-ICT on the web sites of NASA (Vieyra 2014) or CERN (Jende 2015).

2.3 Separate

It is up to the authors of educational material and strategies to separate contexts between the production (i.e. scientific research) and reception of information (i.e. sharing such work with the public). This is especially crucial when accounting for the diversity of students in both expectations and abilities. Different groups of MM users (namely teachers, parents, and students) have different motivations and only well-specified criteria supported by examples can enrich physics learning activities. Suitable examples of teaching and learning tolls in line with this characteristic are for example IVV - interactive video vignettes (Laws 2014) and RCL - remotely controlled laboratories (Lowe 2015).

2.4 Reach

Use of the world wide web network opens a huge number of possible uses and avenues to reach those far removed in time and space from the authors of the materials, information or procedures. The situation is enhanced by the presence of a variety of communication platforms such as social media and blogs which are recognised as spaces where teaching and learning physics also take place. One area, so called iMobilePhysics, is tackling the subject with special attention (Khun 2015).

2.5 Distribute

Distribution concerns not only a way of spreading physics related information but also channels used for sharing physics, and teaching strategies and processes. A well-organized effort towards a ‘one too many’ form of communication is taking place, whereby products are mass-produced and disseminated to a wide audience (via institutional and social networks). The process is visually taking place during education-devoted conferences on one end and during MOOC courses on the other. Distribution seems to be an important factor in building motivation and catching learners attention (Dubson 2015).

3 Perspectives and Concepts

Many institutions that are creating and offering learning activities run different projects and make extensive and often unique use of MM. Based on their own, and shared, experiences a process of optimization is taking place. Because of this, the use of MM is becoming a necessary ingredient in teaching and learning processes. Insightful analysis of MM characteristic, supported by conference presentations, leads to the conclusion that the D-ICT model proposed above describes the situation to some extent but seems to be not useful enough for an educator eager to take advantages of MM in physics teaching. Physic teachers and educators are facing a need for practical hints that could allow structuring of MM and stand as a platform for building teaching and learning strategies. Thus, we would like to introduce SAMR model which allows us to look at the characteristics of MM from a more practical oriented perspective. Two first stages of the model are classified as those of an enhancement while the next two are responsible for transformation in the direction of teaching with use of MM. They contain and complement the D-ICT categorizations previously described.

3.1 Substitution level

At this level, MM are used to support or perform the same tasks as were done before the use of D-ICT. This implies no functional change in the processes of teaching and learning physics. For example, students are still working with traditional on paper worksheets, although they might look modern at first glance as they have been prepared with use of a word editor and professionally printed but do not create functional changes. This education situation tends to be teacher oriented, as an instructor is mostly guiding all aspects of lessons even when D-ICT is used.

3.2 Augmentation level

D-ICT are used here as an effective tool to perform common tasks. There is some functional benefit, as students and teachers can receive almost immediate feedback on their level of understanding of physics topics and concepts. For example, students are filling out the worksheets with use of a computer (or tablet, phone, whiteboard, etc.) or are playing with clickers technology (ex. Testico, Kahoot). On this level, the process of modifying the teacher's role starts and it is moved in the direction of student-centered operation. As the use of D-ICT gives immediate feedback, it might support students in engaging into physics learning.

3.3 Modification level

On this level, the traditional physics classroom situation is transformed into tasks where the use of D-ICT is crucial. Common physics classroom tasks such as observing, writing, experimenting, collecting data, etc. are being accomplished through the use of MM. This implies a significant functional change in the classroom. While all students are performing more or less similar physics activities – on their own or in groups – the reality of interaction and immediate feedback from others (including the apparatus) gives each student personal insight into the quality of the work. D-ICT is then necessary for the classroom to function, allowing feedback from peers, teachers and instruments, as well as visualization. Storage of results from the teaching-learning activities is also permitted.

3.4 Redefinition level

D-ICT allows for performing new tasks that are impossible without the use of MM. At this level, common physics classroom tasks and the use of MM exist, not as ends but as supports for student-oriented learning. Students build knowledge skills and attitudes by performing certain activities strongly involving D-ICT. In this way, collaboration, formulation of questions, discussion and personalized interactions become necessary and only D-ICT allows such actions to occur simultaneously. A variety of key skills can then be shaped.

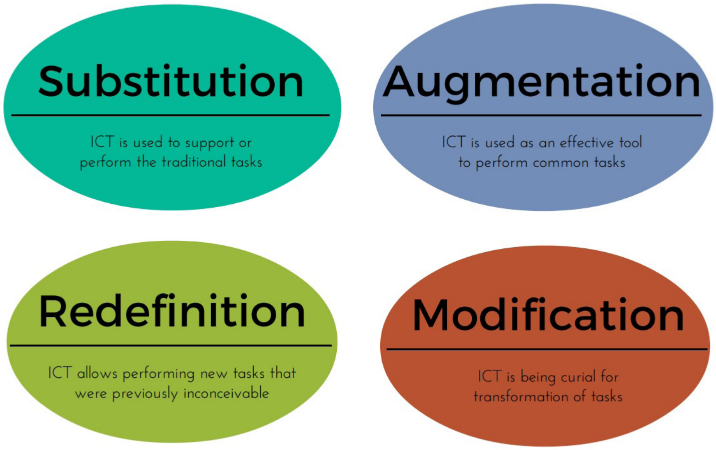

Fig. 1. A complex picture of theoretical aspects related to concepts initializing learning activities with modern media..

4 Conclusions

The process of rethinking the use of D-ICT in physics education should still start with finding the answer to the question: why am I, as a physics teacher, using MM in my everyday teaching of physics? The question is immediately followed by more specific queries about how to convince other teachers to use MM, what specific learning outcomes are, how to ensure the sustainability of the teaching and learning results, etc.

Looking at the wide array of examples with the perspective of mass media can only help a little. It is clear that defining the role of D-ICT in the process of teaching and learning is crucial. The theoretical aspects related to initializing learning activities with MM. (mentioned at the conclusion of the seminar) are presented in fig. 1. In the authors' opinion such a picture seems to be a useful starting point for the discussion of the future outlook and dominating trends in using MM in physics education. The proposed model could also bring about new approaches to the teaching and learning processes. The MM role of enhancement is still central to the transformation aspects needed for further educational oriented research.

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USING SMARTPHONES AND TABLETS AS EXPERIMENTAL TOOLS

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.), *Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning* (pp. 371–377). European Physical Society.

(Kundt, & Vogt, 2013b; Parolin, & Pezzi, 2013, González, & González, 2016), astrophysics (Whiteson, Mulhearn, Shimmin, Brodie, & Burns, 2014), atmospheric physics (Monteiro, Vogt, Stari, Cabeza, & Marti), 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, Marti, Vogt, & Kuhn, 2014, Patrinopoulos, & Kefalis, 2015; Monteiro, Stari, Cabeza, & Marti, 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.

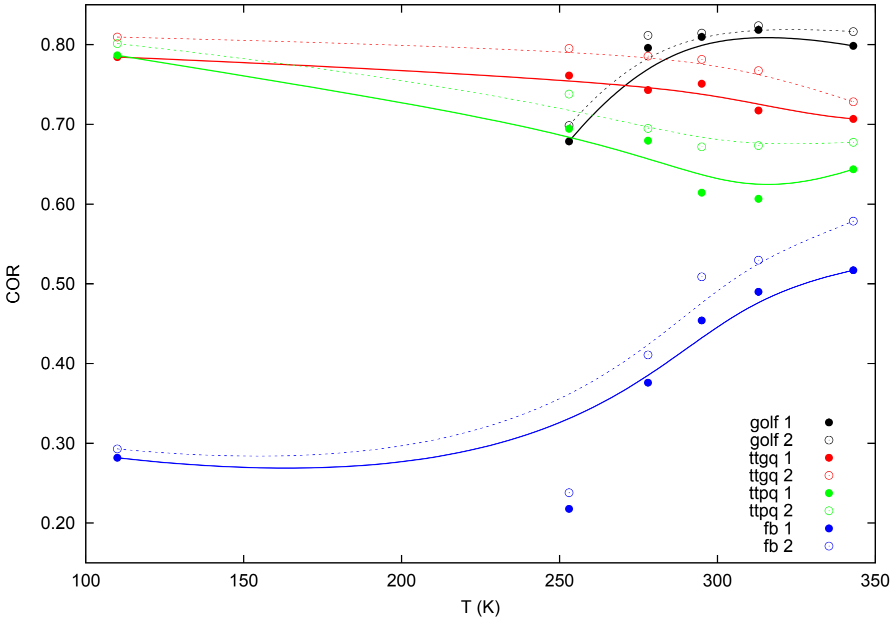

Fig. 1. Dependence of the coefficient of restitution of balls of different materials versus temperature. Two different quality table tennis (ttgq and ttpq), a golf ball (golf) and a foam ball (fb) have been used in the experiment. Results labeled as '1' in the figure correspond to the calculation of 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 (Pendrill, & Rohlén, 2011; Pendrill, 2013; Vieyra,

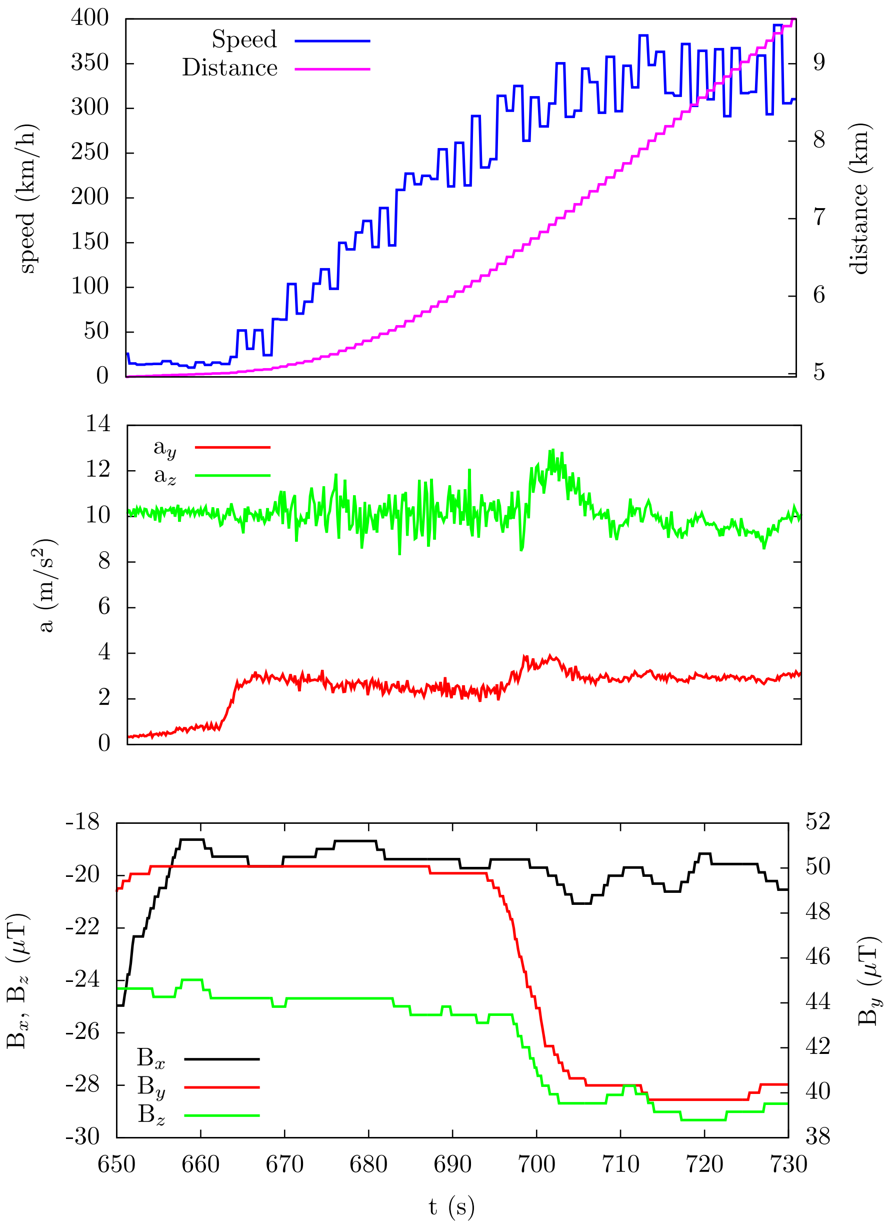

Fig. 2. Simultaneous measurement of acceleration, speed, distance traveled and magnetic field in a plane during take-off, recorded using a Samsung S4 smartphone with the application Sensor Mobile. Students can use measurements like these to understand relationships between different magnitudes and to explain physical phenomena, such as the plane movement along the runaway 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 runaway 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 runaway 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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Multiple Smartphones Interests as Educational Tools in Digital Active Classes

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Institut Français de l'Education, France

Mobile devices are increasing students' opportunities to access knowledge in their classroom, home and social network, and are changing the organization of teaching and learning models. Student-teacher interactions, spaces in and out of class and the erosion of barriers between disciplines are a few examples of this change. A team of 25 teachers in middle and high school, in physics, biology, geology, math, languages, geography, philosophy and economy worked on this subject. This included exploring new opportunities for teaching with smartphones (and other kind of mobile devices), their sensors, their connectivity, their mobility and their computing power. The goals of this team are:

- to design and carry out activities with mobile devices.
- to observe the activities of their colleagues
- to analyze the benefits and limits of mobile device usage during teachers' activities
- to share teachers' exploration with the community thanks to a website and teachers training. (http://acces.ens-lyon.fr/acces/classe/numerique)

Four physics teachers of this team explored different ways to use the students' smartphones for different activities in their class. This article focuses on the practices, benefits and constraints related to the use of smartphone sensors for activities in class.

1 Context

Even though they were not designed for this purpose, smartphones have a lot of advantages when used for teaching. They can take pictures, videos, and record sounds. They have a touchscreen, the power of a computer, and many sensors, most of which can be used for physics experiments. Smartphones feature accelerometers, gyrometers, magnetometers, and a GPS. The microphone, camera and antenna can also be used as sensors. Some smartphones even have a pressure sensor and a thermometer.

Many students have their own smartphone. For instance, in France in 2015 50% of people over 11 have a smartphone. (1). For students, the rate can be as high as 75% or more.

When we check in our classes, most students (60%) have an Android device, 35% have an IOS device and others have a Windows mobile device (the equivalent of 0 to 2 per class).

In this context, when we prepare an activity, we have to find an application for each system. It is easy to find applications for Android and IOS but it is more complicated to find one for Windows mobile. In our activities, we will just give the application for Android and IOS. We did not find a suitable application for Windows mobile devices.

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2 The group of teachers, our field of research.

We are teachers of different disciplines, and started working on this project 3 years ago. We explored two subjects. The first subject is to find the most efficient way to flip the classroom. The second subject is how to teach with new mobile devices, tablets and smartphones. Here we will focus on the smartphones with the students bringing their own.

We explored 3 different ways to use smartphones in our class. The first method can be applied to every discipline, it is the use of the smartphone as a learning management tool —a means to create interactive teaching with smartphone. The second involves using the smartphone as a tool of report for experimental activities, such as how to read instructions and how to report with a smartphone. It can be used in all kinds of experimental sciences. The last method concerns using the sensors of the smartphones and obtaining different measurements during practical activities in physics and chemistry. In this article, we will focus on the use of the sensors during practical activities.

Our group has 25 members of different disciplines, but for this study we will take into account only the work of 4 physics and chemistry teachers. Two of us work in middle schools, with pupils aged 12 to 15. The others work in high schools, with pupils aged 16 to18 years old.

3 Procedure for using the smartphones with the pupils

As the students have to bring their own device, we have to check different things before the day of the activity.

First, we have to check with the principal of our school and the administration that there is no limitation to the use of smartphones in our classes. You can find some hints on page 69 of the Istage2 *"Smartphones in science teaching"* booklet:

(http://www.science-on-stage.de/page/display/en/7/7/678/istage-2-smartphones-im-naturwissenschaftlichen-unterricht1).

To be sure that the parents are aware of and agree to this activity, we can ask them to sign a form. There are some examples of forms on our website; they can be downloaded here:

http://acces.ens-lyon.fr/acces/classe/numerique/smartphones/ressources/administratif

As the pupils use their own devices, it is important to use free apps. We provide a list of free apps for each activity:

http://acces.ens-lyon.fr/acces/classe/numerique/smartphones/ressources/tutoriels/

In some cases we have the same app for both systems.

To avoid any problem linked with the lack of Wi-Fi at school, it is best to give out the list of the applications a few days before the activity. The students can download them at home. The teacher can also give the instructions to use the application beforehand. The tutorial can be a video:

http://acces.ens-lyon.fr/acces/classe/numerique/smartphones/ressources/tutoriels/mode-d2019emploi-etude-de-l2019acoustique-musicale-avec-des-smartphones/

Finally, we have to check who can bring a smartphone to prepare the groups for the activity.

4 Using the smartphones in class.

4.1 Activities with the sensors.

We explored different areas of physics where the use of smartphones provides more opportunities to measure new data, allows for easier work or increases the accuracy of the measurements.

Smartphones can prove very useful tools to work on the following areas:

- Acoustics (one can measure the frequencies of sound and music, study acoustics and sound levels, and measure the Doppler effect)

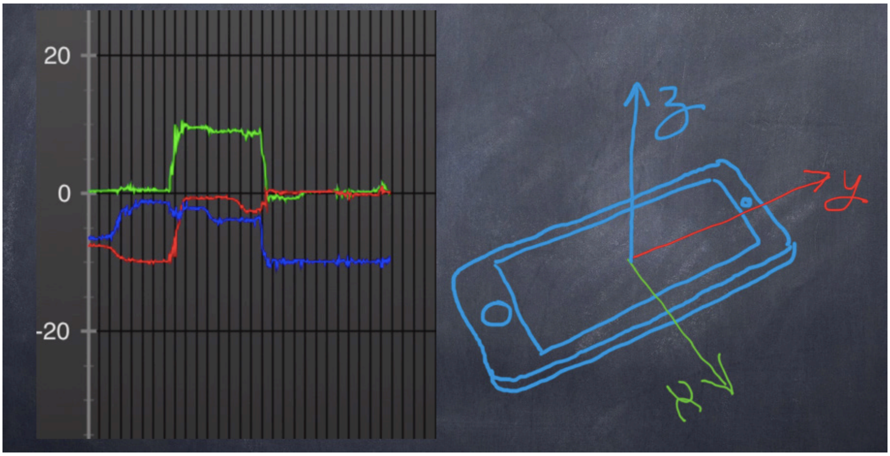

Fig. 1. On the left the screenshot of the sensor kinetics display, on the right the axis of the smartphone (is this case for iOS, the direction of the axis depends of the smartphone).

- Mechanics (acceleration in different conditions can be measured)
- Fields (direct measurement of the magnetic field is also possible)

We tried other activities, such as measuring the heartbeat, making a microscope with the phone, and using the smartphone as a theodolite. Some smartphones can also measure pressure.

The following examples were tested several times in class. For each case we noticed than the activity is easier to manage, and proceeds faster with smartphones than without. The activity is easy to set up, smartphones feature sensors with a simple data acquisition system and are easy to manage. The students can develop their skills in physics without the difficulties associated with data acquisition devices.

4.2 Mechanics and the measure of the acceleration.

For the activities on acceleration, we used Sensor Kinetics, it is a free application, available for android and IOS where we can zoom in easily to get the value of the acceleration.

Most smartphones are provided with a 3D accelerometer which can measure the acceleration along three axes. One possible activity involves finding the axis of the 3D accelerometer with the acceleration of gravity and the display of the smartphone (fig.1)

With real time measurement of acceleration, the students can check Newton's laws during activities in school and also outside the school. The students can also study motion, for instance circular motion.

For circular motion, we designed an inquiry-based activity. The student must find the position of the accelerometer inside the smartphone with the help of a turntable (record player). The student has an instruction form with data about the record player, circular motion and the application. It's determine the procedure to get the position of the accelerometer inside the smartphone

See: (https://www.nsta.org/store/product_detail.aspx?id=10.2505/4/tst15_082_09_32) and (http://bit.ly/smartphonerecordplayer)

The activity is also on video: https://youtu.be/cTxMuzmcPII

4.3 Acoustics, waves properties, and the Doppler effect.

In this case, we used the connection between the motion of the smartphone, the Doppler effect of sound waves, and the radial velocity method to find exoplanets.

During the activity, the students have to find the velocity of a smartphone. The smart-

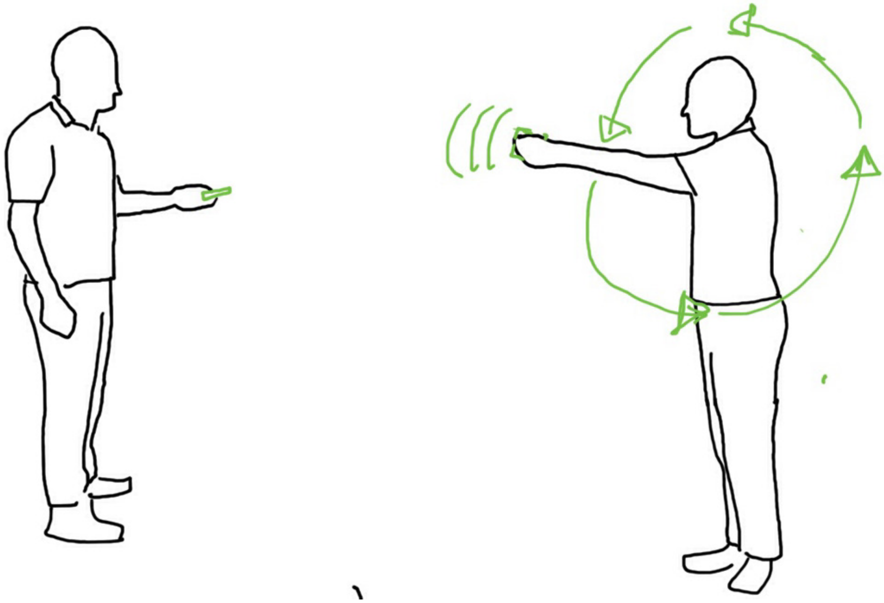

Fig. 2. On the left, the student measures the frequency of the sound emitted by the smartphone moved by he teacher on the right..

phone is moved by the teacher or by another student. The teacher gives a circular and uniform motion to the smartphone (fig 2)

The student has to measure the frequency of the sound with his phone. The frequency changes according to the Doppler effect. With the Doppler effect formula of the sound wave, the student can find the speed of the phone during rotation.

The same method is used to measure the radial velocity of stars and find exoplanets. Stars move when planets revolve around them. If one star has one planet, then the star has a circular and uniform motion. This motion changes the wavelength of the electromagnetic waves emitted by the star. Astronomers measure the variation of this wavelength to get the velocity of the star.

We practiced this activity more than ten times with different classes. The experiment is easy to set up and the students have more time to understand the physical phenomenon.

More details on this experiment: http://bit.ly/edusmartphone

4.4 Eratosthenes measure with smartphones

This activity is based on the link between a historical measure and a modern device. The smartphone takes the place of the gnomon, the stick used to get the altitude of the Sun. With smartphones, the experiment is simpler than with the gnomon and does not require using trigonometry. In the Eratosthenes measure, the students have to determine the altitude of the Sun. Here, to get the altitude, the student has to align the camera in their phone with its shadow. Various applications then give the inclination angle of the smartphone. This angle is the altitude of the Sun (fig 3 and fig 4).

The lesson plan is here: http://bit.ly/JEA-eratosthene2

With a video: http://bit.ly/JEA-eratosthene

4.5 Measure of the heart rate.

We performed this activity at the beginning of high school, with students aged 15-16. In this activity, the students study periodic phenomena and measure the period and frequen-

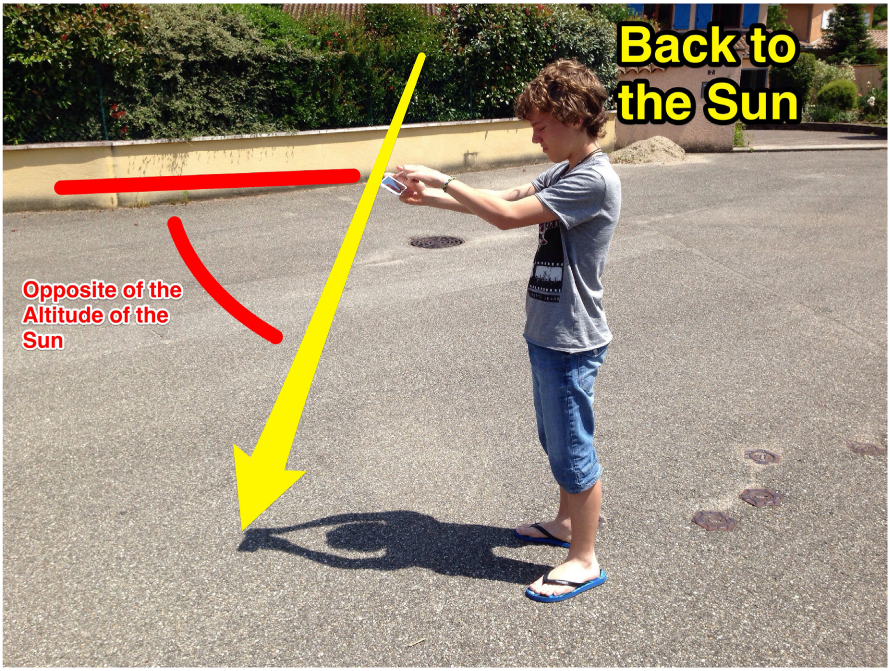

Fig. 3. How to measure the altitude of the sun. The student measures the opposite (-) of the altitude.

cy, showing the link between them. This activity is so easy to set up that most of our physics colleagues in our schools did it with their classes. With a specific application, the students measure their heart beat rate with the camera and the flash bulb of the phone.

See the tutorial here: http://bit.ly/h-rate

5 Others examples of using mobile devices (12 to 15 years old).

In this part, one teacher of the group gives his procedure to use mobile devices in his classes. He gives also examples of activities in classes with pupils'smartphones.

Jean-Luc Richter is working with students from 12 to 15 years old in a "college" in Marckolsheim (Alsace-France). He was one of the coordinators of the Science on Stage iStage 2 booklet: *"using smartphones in science teaching"*. In his classroom he uses smartphones on several occasions as a scientific measuring tool during the day to day teaching process as well as in school projects.

Before using smartphones, the students and their parents have to sign an agreement concerning responsibility. The teachers have to convince the staff to allow the use of mobile devices, which is usually forbidden. The teacher decide to trust the students not to use social networks during teaching hours after explaining to them the opportunity he gives them to use their own devices. No student broke these rules during the two years of "experimenting" so far. After a few month of experimentation, other teachers in the school joined M. Richter by using the same tool with their students.

Smartphones can also be used as mobile cameras to show small experiments to all of the students and to help students by learning from each other. For example, during a group experiment, if one of the groups has a problem, the teacher can demonstrate what to do with his smartphone. The image can be sent to the projector and all other students see what's happening and can think of a solution to help the group in question. Students can make photos of experiments with smartphones and tablets to make a report of their work. Some students, using iPad tablets, use the app "comic life" to present reports in a comic

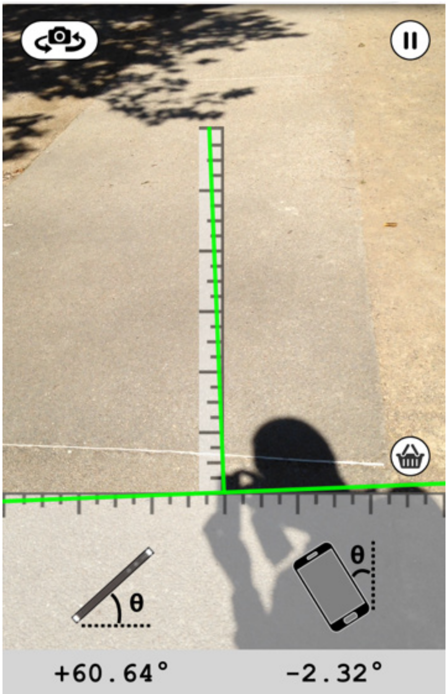

Fig. 4. Screenshot of the smartphone with the altitude of the sun, here 60.64°.

book style, which helps them retain the main steps of an experiment.

One school project is to make a map of the sound level in different parts of the school. Noise is a big problem because of various architectural decisions which do not account for the use of the building to host teenagers. After having calibrated their smartphones with pink noise in a quiet classroom during lunch break, a group of twenty volunteer students measures the average sound level in all the rooms of the school, including the canteen, the courtyard, hall and sport hall. They compile the data in tables and transmit to the school council a list of very noisy places in the hope solutions will be found to reduce the noise level.

During the solar eclipse in 2015, where 77% coverage was observed in the area near the school, a group of fifteen students, and the headmaster, made a measurements of the light emitted by the sun. Helped by a fortunate cloud free sky and a total absence of humidity, they used their smartphones to measure the light level every 15 minutes against a white wall and found out that the light level decreased by about 75% (very near to the theoretical value) even though the eyes could not really "see" the difference (due to our automatic adaptation to the light level).

The ability to measure atmospheric pressure directly with a smartphone is used during physic lessons about pressure to show the relationship between pressure and altitude, and to measure pressure inside a vacuum dome by showing the pressure measurement through a wireless lan connexion.

Smartphones are not only used in physics: one art teacher in our group uses the camera of student's smartphones almost every day to study geometric figures in relation to painting and optical illusions. In biology, the use of a "Micro Phone Lens", which provides a picture with a magnification of 150, allows the teacher to take pictures of observations that usually must be drawn. This helps save time and allows for the study of more samples.

6 Conclusion and outlook.

All the above activities demonstrate that the use of smartphones has a lot of advantages for practical work in physics. Smartphone sensors are easy to use with the applications. Students have no difficulty in setting up their smartphones. Smartphones are user-friendly. The students can focus more time on understanding the physical phenomenon studied with their device. The field of study is very wide. It evolves a lot with the new sensors in the phones, such as the pressure sensor.

However, the use of smartphones means that the students bring their own device. The teacher has to prepare his activities very carefully.

This working method also has other advantages: schools do not buy the device, they are the students' property. And the teacher does not have to perform the maintenance of the device.

This article describes a small part of what can be done with smartphones in class. Since smartphones and their uses evolve quickly; our group will continue to explore new activities. Follow us on the website:

http://acces.ens-lyon.fr/acces/classe/numerique/smartphones

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INCORPORATING MULTIMEDIA AND ICT IN PHYSICS EDUCATION: FOCUS ON LEARNING PATHS AND ASSESSMENT

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.

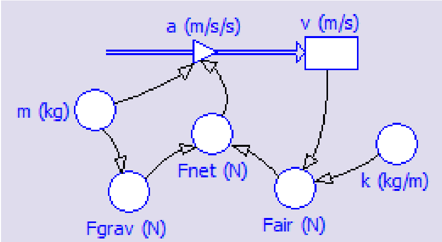

Fig. 1. Graphical model for the velocity v of an object falling through air. The motion of the body is governed by the difference equation $\Delta v = a \cdot \Delta t$, in which the acceleration a is defined as $a = F_{net}/m$, where the net force F_{net} equals the force of gravity F_{grav} minus the air resistance F_{air}. The air resistance is defined as $F_{air} = k \cdot v^2$, 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.

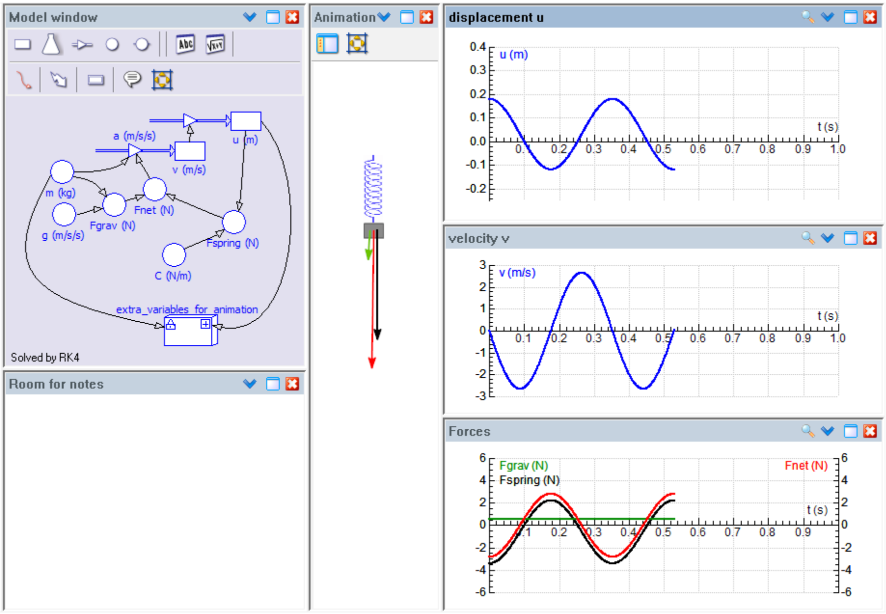

Fig. 2. Shot of part of the screen from a modelling activity in the first year of upper secondary education. A graphical model for a mass attached to a string in the upper left window drives an animation in the window in the middle. The vectors for the force of gravity F_{grav} , the spring tension F_{spring}, 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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