25th International Workshop on Multimedia in Physics Teaching and Learning
8-10 September 2022
Wrocław, Poland

Hosted by University of Wrocław, Faculty of Physics and Astronomy,
Institute of Experimental Physics
pl. M. Borna 9, 50-204 Wrocław

Book of Abstracts

Main topic of the workshop

Physics Teaching and Learning with Mobile Technologies

Subtopics

A. Enhancing the use of multimedia and technology in Physics Teaching and Learning.
From good practices to new possible approaches to specific physics content.

B. Modern equipment and technology to improve Physics Teaching and Learning.
From productive use of modern equipment and technology to lessons strategies and curriculum modifications.

C. Challenges and opportunities of use of multimedia including distance learning.

Editors
Tomasz Greczyło, Ewa Dębowska, Robert Bryl

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Program

8 September 2022, Thursday		
12:00 - 12:30	**Opening ceremony** Speakers: Tomasz Greczyło, Lars-Jochen Thoms, Michał Tomczak Dean of Faculty of Physics and Astronomy, University of Wrocław	60 (1st floor) 164 (2nd floor)
12:30 - 14:00	**Keynote** (chairperson: Lars-Jochen Thoms) Digital Competences and Physics Education – Perspectives for Classroom Practice and Teacher Education Speaker: **Andréas Mueller**	60 (1st floor) 164 (2nd floor)
14:00 - 14:45	**Lunch**	119 (2nd floor)
14:45 - 16:15	**Workshops I**	
	I.1 (room 320, 4th floor) Thermal Imaging Camera in Physics Hands-On Experiments Leader: **Petr Kácovský**	**I.2** (room 511, 6th floor) Using Low-Cost and Standalone Virtual and Augmented Reality Headsets to Teach and Learn Motion Concepts Leader: **Tommaso Rosi**
16:15 - 16:45	**Coffee break**	119 (2nd floor)
16:45 - 17:45	**Poster presentations** Presenters: Petr Kácovský, Zdeňka Koupilová, Robert Teese, Ralf Widenhorn	hall - 2st floor

9 September 2022, Friday		
9:00 - 10:30	**Keynote** (chairperson: Tomasz Greczyło) Using phyphox for innovative teaching-learning situations in physics Speaker: **Jens Noritzsch**	60 (1st floor) 164 (2nd floor)
10:30 - 11:00	**Coffee break**	119 (2nd floor)
11:00 - 12:00	**Workshops II** Using Phyphox for Innovative Teaching-Learning Situtations in Physics Leader: **Jens Noritzsch**	320 (4th floor)
12:00 - 12:30	**Coffee break**	119 (2nd floor)
12:30 - 13:30	**Presentations I** Speakers: **Ralf Widenhorn** - Using a 3D Camera and a Local Positioning System in Physics Instruction **Lars-Jochen Thoms** - Simple experiments to observe and analyse Haidinger's brush with a smartphone	60 (1st floor) 164 (2nd floor)
13:30 - 14:30	**Lunch**	119 (2nd floor)
14:30 - 16:00	**Keynote** (chairperson: Robert Bryl) Compute shaders in physics education Speaker: **Maciej Matyka**	60 (1st floor) 164 (2nd floor)
16:00 - 16:30	**Coffee break**	119 (2nd floor)
16:30 - 18:00	**Workshops II**	
	II.1 (room 320, 4th floor) Student Laboratory for Conductivity – a Low-Cost, Easy and Fun Project for Students Leader: **Dorottya Schnider**	**II.2** (room 511, 6th floor) Imaging in Physics Education and in Science Popularization: an Introductive Workshop Leader: **Peppino Sapia**
19:00	**Workshop dinner**	Restauracja Dwór Polski Rynek 5, 50-106 Wrocław www.dworpolski.wroclaw.pl

10 September 2022, Saturday		
10:00 - 11:30	**Keynote** (chairperson: Ewa Dębowska) How Computers Improve Physics Teaching Through Interactive Engagement Speaker: **Wolfgang Christian**	60 (1st floor) 164 (2nd floor)
11:30 - 12:00	**Coffee break**	119 (2nd floor)
12:00 - 13:00	**Presentations II** Speakers: **Masoud Seifikar** - Students' Perspective on the Classroom Response Systems in Physics Classrooms **Francisco Esquembre** - WebEJS: A fully Web-Based Version of Easy JavaScript Simulations	60 (1st floor) 164 (2nd floor)
13:00 - 13:30	**Coffee break**	119 (2nd floor)
13:30 - 14:30	**Presentations III** Speakers: **Marina Babayeva** - Implementing Virtual Instruments to Increase Knowledge Comprehension and Engagement Rate in Distance Physics Teaching **Joerg Zumbach** - Visualization and Metacognitive Scaffolding in Learning from Animations about the Anomaly of Water	60 (1st floor) 164 (2nd floor)
14:30 - 15:00	**Closing ceremony** Speakers: Tomasz Greczyło, Lars-Jochen Thoms	60 (1st floor) 164 (2nd floor)
14:30 - 15:00	**Teachers' workshop** (in Polish) *Wykorzystanie cyfrowej biblioteki Open Source Physics Simulations oraz aplikacji Tracker Video Analysis and Modeling* Leaders: **Wolfgang Christian,** Tomasz Greczyło	124 (2nd floor) 128 (2nd floor)

Keynote 1

Digital Competences and Physics Education – Perspectives for Classroom Practice and Teacher Education

Andréas MUELLER

University of Geneva, Faculty of Science/Physics Section, Institut Universitaire de Formation des Enseignants (IUFE), Switzerland

Abstract. Recent work in research & development using smartphones or tablet computers and theirs sensor for physics education will be reviewed, with a focus on intended competences and other educational objectives to be achieved with this approach.
Based on empirical outcomes and on the current intense discussion on multimedia and other digital tools for educational purposes, several promising perspectives for classroom practice and teacher education are presented for discussion.

Keynote 2

Compute Shaders in Physics Education

Maciej MATYKA, Dawid STRZELCZYK

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Abstract. Recent development of fast graphics processing units (GPUs) used mainly for rendering high quality graphics, computing advanced machine learning models or even digging some bitcoins have opened new perspectives for education. Some of us remember computing real-time 100x100 game of life models in computer lab of modelling course. Today, full 4K resolution (by saying that we mean 3840x2160) in 60FPS is possible. We will show that today's hardware can be used as a framework for computer simulations of realistic physical processes at scale and rates that makes the educational experience satisfying for young generation.

Keynote 3

Phyphox – a Hand Full of Physics

Jens NORITZSCH

2nd Institute of Physics A, RWTH Aachen University, Germany

Abstract. Almost all teens or young learners have smartphones. The free app phyphox turns these – or tablets – into versatile mobile labs. This makes it possible to conduct scientific experiments away from the lab equipment and specialised tools, proving particularly beneficial at times.
Some examples and ideas as well as ways to expand the potential are presented.

Keynote 4

How Computers Improve Physics Teaching Through Interactive Engagement

Wolfgang CHRISTIAN

Davidson College, North Carolina, USA

Abstract. Do computers foster interactive engagement, or do they inhibit creative thinking, human interaction, and attention spans? Have computers fundamentally improved how we teach and learn physics? This talk presents a personal history of how computers and the internet have challenged me and changed how I teach. I present examples to show that computers can provide a learning experience that utilizes students cognitive, affective, and psychomotor domains of learning.

Using Low-Cost and Standalone Virtual and Augmented Reality Headsets to Teach and Learn Motion Concepts

Tommaso ROSI, Pasquale ONORATO, Stefano OSS

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Abstract. Low-cost, standalone Virtual Reality (VR) and Augmented Reality (AR) headsets are today available to teachers and researchers, creating new opportunities for educators similarly to what happened with smartphones and the BYOD methodology. In fact, these VR/AR setups are based on high-precision, 6 degrees-of-freedom, high-speed, multiple-object tracking technologies, whose data is available to developers to build their (educational) experiences. During this workshop we will present the software to teach and learn motion concepts we developed; participants will be able to use standalone headsets for hands-on activities and to debate the potential and limitations of this technology in its use in Physics Education.

Virtual Reality as a Physics Education Tool

Virtual Reality (VR) is a technology which researchers have been experimenting on for more than fifty years. Yet, only in the past decade we have seen it become mature enough from a commercial point of view so that any non-experienced user could use it and have a truly immersive and interactive experience. Today, low-cost, standalone headsets are available to gamers, teachers and researchers, which have a very low barrier in order to be used by any new user.

This creates a new opportunity for educators, similarly to what happened with the smartphone revolution and the development of the BYOD methodology [1] of the past twenty years. Similarly to smartphones, these headsets are also computing devices which also heavily rely on very high quality sensors, which by definition is something that physics educators are always interested in.

In particular, the immersivity and interactivity required by VR experiences are based on high-precision, 6 degrees-of-freedom, high-speed, multiple objects tracking technology: the position and rotation of the headset and of (typically) two controllers must be known at any time to have a high-quality experience. This is the reason why these setups show a great potential to be adopted as a powerful tool in teaching and learning motion concepts in the laboratory of physics.

Augmented Reality

Another aspect to not be underestimated is the capability of introducing Augmented Reality (AR) in the classroom using the same VR headsets we have been talking about. This is possible as the tracking of these standalone headsets relies heavily on multiple cameras which are scanning the physical world surrounding the user and recreate a 3D representation of it to know its position and rotation. Users and developers can access these cameras information thanks to the so-called “passthrough” technology, in which the users can see digital information blended with their physical surroundings (Fig. 1). In contrast to Virtual Reality, which by definition is an immersive experience which can be completely unrelated to your surroundings (in general it is designed to be so), Augmented Reality aims to a blending of digital information with the physical world surrounding the user. Again, this is something which physics educators could take a huge advantage of. A simple example of this is represented in Fig. 2 left, in which information of the motion of a tracked controller is displayed not in a virtual environment but in an AR environment.

This opens up to the possibility of easily interacting with other more traditional experimental apparatuses of the laboratory of physics, such as rotating objects, low-friction carts and pendulums (Fig. 2 right).

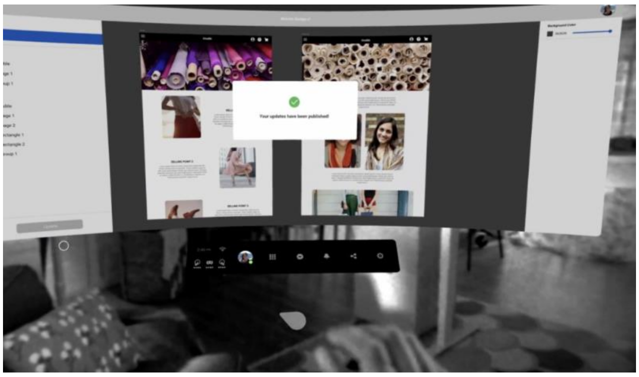

Fig. 1. Passthrough technology is an AR experience in which users can see digital information blended with their physical surroundings using cameras installed on their headsets.

Fig. 2. Left: tracking information of a controller displayed in real-time using AR. Right: tracking data of two controllers attached to a rotating platform are displayed in the same way, also adding charts about the tracked motion.

The workshop

In this workshop we will present the software to teach and learn motion concepts we developed; participants will be able to use standalone headsets for hands-on activities and to debate the potential and limitations of this technology in its use in Physics Education. The authors believe that this technology is mature enough to be another tool to teach and learn motion [2] that has to be thoroughly analysed by Physics Education researchers as it has been done (and still is) for MBL activities [2], video tracking [3,4] and simulations [5].

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Workshop 2 (#6, subtopic B)

Thermal Imaging Camera in Physics Hands-On Experiments

Petr KÁCOVSKÝ

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Abstract. The workshop consists of more than twenty simple hands-on physics experiments that use a thermal imaging camera as a visualization tool. These experiments are grouped thematically into six experimental sets, namely: thermal conductivity, conversion of kinetic energy into internal energy, evaporation of liquids, light sources, heating by radiation and Joule heating. All the experiments are designed primarily for upper secondary students, but they are also usable with younger ones. The participants will be provided with a thermal imaging cameras and in groups of up to three will gradually explore a particular experimental set.

Thermal imaging camera in physics teaching and learning

Thermal imaging (also infrared thermography) is a procedure of evaluating the surface temperature of a measured object by analysing thermal radiation emitted by its surface. Although it was originally used mainly in industrial applications, thermal imaging in recent years has become a commonly used visualisation technique in science education as well. Especially physics teaching and learning offers plenty of opportunities for involving thermal imaging camera to uncover ongoing thermal processes that are invisible to our eyes.

There were published many suggestions on how to use thermal imaging in physics lessons [1-7], not just when teaching thermodynamics, but also when studying thermal effects in mechanics or electromagnetism [8-9]. The growing number of established experiments has also enabled research studies on the impact of using thermal imaging cameras on students [10-11].

For a long time, the high price of thermal imaging cameras meant that they were mainly used for demonstration experiments, as it was unthinkable for schools to purchase more than one camera. Without exaggeration, this has been revolutionised by the advent of modules that are not stand-alone, but connect to smartphones or tablets and use their display [12]. These modules (e.g. Flir One Pro, Seek Thermal Compact, etc.) make it possible to equip a classroom with so many cameras at a reasonable price that they can be used for either group work in labs or any other inquiry based activities. This is the reason for designing the sequence of activities presented in this workshop.

Experimental sets prepared for the workshop

For the purposes of the workshop, the particular experiments were grouped thematically into six experimental sets that are listed below, with short description of what phenomena are studied:

- *Thermal conductivity* – comparing conductivity of thermal conductors and insulators, comparing conductivity of two different metals.
- *Conversion of kinetic energy into internal energy* – change in internal energy by performing work, frictional heating.
- *Evaporation of liquids* – evaporative cooling in water and ethanol, condensation of water vapours.

- *Light sources* – waste heat produced by incandescent bulbs, compact fluorescent lamps and LED bulbs, convection of the protective atmosphere of a tungsten fibre in the incandescent bulb.
- *Heating by radiation* – absorption, reflection and transmission characteristics of different materials.
- *Joule heating* – visualising Kirchhoff's laws by measuring the temperature of resistors in simple DC circuits.

Organisational form

The introduction of the workshop (ca. 15-20 minutes) will be held frontally and its goal will be to summarise basic physics principles of thermography. Within this part, also the main obstacles and tricks will be emphasised, especially the influence of emissivity and reflected temperature on the actual temperature readings. After that, participants create groups of up to three; every group will have a thermal imaging camera at their disposal. Gradually, every group can go through all the six experimental sets, guided by prepared worksheets (ca. 60 minutes).

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Workshop 3 (#10, subtopic B)

Student Laboratory for Conductivity – a Low-Cost, Easy and Fun Project for Students

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Abstract. Classroom experimentation plays a crucial role in physics education. With the use of Arduino-systems, we have the opportunity to create low-cost equipment for the physics lab, and conduct various interesting and practice-oriented measurements with our students, from basic experiments to advanced-level research problems. Testing the conductivity of different fluids can be useful for this purpose. Working in small groups, students can not only investigate the effects of different physical and chemical parameters, but also, they have the opportunity to learn how to process and evaluate data, thus the project develops digital competences, too.

Arduino – not only for programming

An Arduino microcontroller can be applied for teaching different topics of physics [1]. Because these devices are quite cheap compared to many other educational tools, it is worth looking for its new usages and good practices. One such idea is the investigation of the conductivity of fluids [2] with Arduino, and processing the measured data using the free Excel-Add-In software, called Data Streamer [3]. The project presented below includes a 3x 60-minute-long activity, which was designed for a student exchange program. Because of its simplicity, diversity and its role in competence-development, it is worth dealing with in our physics lessons. In our workshop, we present the details of this practice-oriented activity and offer a fun project for colleagues.

What can we measure?

In the course of the measurements, all we have to do is measure the voltage, and we can use the data for further analysis and calculation, e.g., to determine the conductivity of the tested liquid using a known resistance. The principle of the measurement setup is shown in Figure 1.
Examples of parameters for a liquid, which can range from distilled water to acidic or alkaline electrolytes, including salt or citric acid content, pH value (measured with external device or with indicator stripes), temperature and geometric shape.

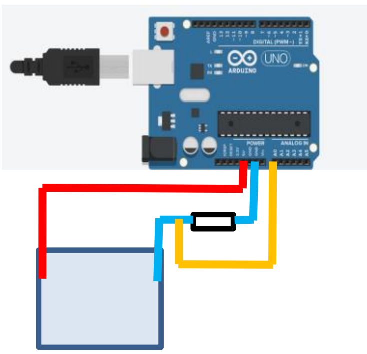

Fig. 1. Principle of the measurement setup.

Program code and data analysis

In order to conduct measurements, students have to use and understand the basic program code (Figure 2), that is needed to operate the sensors.

```
int input= A0;
int voltageValue = 0;

void setup()
{
Serial.begin(9600);
}
void loop()
{
voltage Value=analogRead(input);
Serial.print("Voltage in mV= " );
Serial.println(voltageValue/1024*5000);
delay (50);
}
```

Fig. 2. The basic program code to operate sensors.

Data can be analysed by reading the measured data and do calculations on paper, or students can use a software for analysing the investigated values. Using Data Streamer can be very useful for time dependent measurements. The result of a short part of the project can be seen in Figure 3.

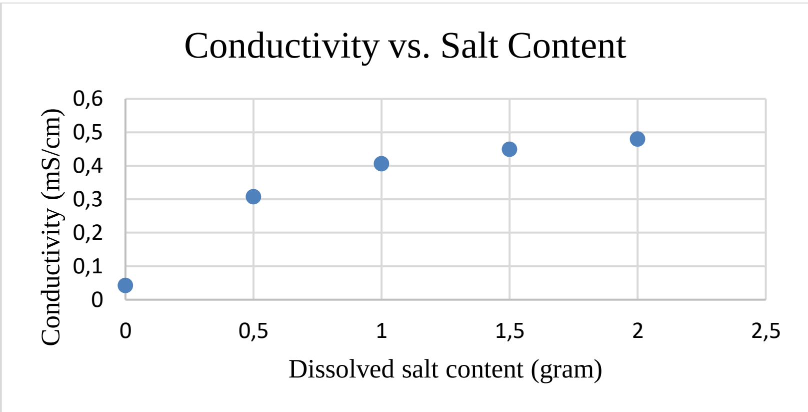

Figure 3. A typical result.

Based on the measurement results, our students can either discover qualitative correlations on their own or test quantitative models.

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Workshop 4 (#11, subtopic B)

Using Phyphox for Innovative Teaching-Learning Situtations in Physics

Jens NORITZSCH

2nd Institute of Physics A, RWTH Aachen University, Germany

Abstract. The free app phyphox has a set of beneficial features for smart-device-based physics experiments utilising particularly the built-in sensors [1, 2]. Notably, a high level of customisation, diverse options for data analysis, a remote interface, and a versatile interface for network connections like wi-fi or Bluetooth LE offer opportunities for innovative teaching-learning situations.

In this workshop, participants will explore these features as well as the range of competences desired for teachers –and learners– to enable productive use of everyday smart devices. Examples are provided from the areas of teaching, research, and day-to-day inquiries.

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Workshop 5 (#16, subtopic B)

Imaging in Physics Education and in Science Popularization: an Introductive Workshop

Peppino SAPIA (1,2), Giacomo BOZZO (1,3)

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(2) Department of Biology, Ecology and Earth Sciences, University of Calabria, Ponte Bucci, 87036 Rende CS, Italy
(3) Scientific High School "G.B. Quadri", Vicenza, Italy

Abstract. In this workshop we will share our experience in implementing advanced imaging techniques in scientific educational and dissemination contexts, by making use of educational grade devices and easily available materials. Participants will be provided with an overview of various educational grade imaging techniques and they will have the opportunity to acquire basic operational skills on image processing regarding some of these techniques.

Introduction

Visualisation (of real phenomena, of thought experiments, of analogical models) is recognised as a fundamental resource for both the learning and communication processes of science [1-3]. In particular, visualisations as educational methodologies are acknowledged as factors “that may facilitate students’ construction of mental models for scientific information” [4].

In the vast field of visualisation techniques and methodologies, a special role is played by those aimed to produce images of real objects and phenomena, i.e. the imaging techniques. These can be done both in the visible and/or the infrared spectral bands; they can produce static images, or movies, either at normal speed or high-speed, as well as time lapse videos [5-14].

Imaging of scientific subjects and natural phenomena requires both:

a) practical skills in using various kind of cameras (for still images or motion pictures), including some specialised optics (e.g., micro lenses) and lighting systems (e.g., UV for fluorescence imaging);
b) theoretical knowledge on the digital representation of images, and practical skills in applying such knowledge to image processing by means of software application, possibly free [e.g., 15, 16, 17].

Aims of the workshop

Participants will gain knowledge and some basic skills on:

- Educational grade imaging techniques, including: microphotography [18, 19], fluorescence contrast imaging [20], high speed micro imaging [21].
- False colour processing of multi band images, including NIR band [14, 22].
- Surface 3D microtopography, based on a simple optical microscope and the use of free image-processing software [13].

In particular, participants will be involved in image processing practical activities, on both surface 3D microtopography and false colour processing technique. To this end, organisers will provide participants with pre-recorded images of real subjects.

Practical information

Participants are expected to bring their own devices (laptops or tablets), taking care to install the free Fiji [16] and Gimp [15] software (Adobe Photoshop can be an alternative to Gimp). At least one week before the event, organizers will invite, by email, the registered participants to complete an anonymous questionnaire on their image processing knowledge and skills, in order to enable the optimal planning of the activities that will be proposed during the workshop.

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Oral presentation 1 (#2, subtopic B)

New Pendulum with Different Types of Friction Motion at Large/Small Amplitudes - Smartphone Compatible

Giacomo TORZO

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Abstract. We present a new simple didactic tool that uses real-time data acquisition via smartphone or tablet and a pendulum coupled to a low-friction rotation sensor, with variable effective length and mass, and with two different types of adjustable damping: "*sliding*" friction and “*Viscous*” friction (proportional to the angular velocity)

Introduction

The motion of the pendulum is considered the harmonic motion par excellence (isochronism of small oscillations) but for large oscillation amplitudes, consequent to the fact that the equation of motion is not linear except in the approximation of small angles, the deviations from isochronism can exceed 50%. It is therefore an experimental topic that allows us to *observe the main characteristics of both harmonic and anharmonic motion*.

The experimental study of the pendulum is made more effective by using on-line da acquisition often referred to as Real Time Laboratory.

Our proposal

The elements that make up our device are: *datalogger*, *rotation sensor*, *rod*, *rubber ball*, *aluminum disc*, *magnet* mounted on slide, *brush* mounted on slide. The sensor and the two slides are mounted on an *aluminum rail*, equipped with a *vice* that allows it to be fixed to the edge of a table (see Figure 1).

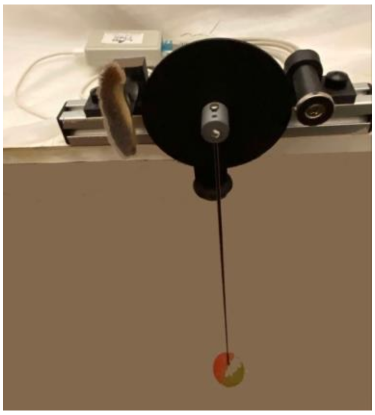

Fig. 1. Pendulum with datalogger connected via bluetooth with smartphone/tablet/pc

The pendulum consists of a rubber ball inserted on a thin (carbon-fiber) rod attached to the pivot of an angle-sensor with *very little friction*.

In order to study both *viscous* and *sliding* friction, an *aluminum disk* is fixed to the sensor axis. In this way the oscillation of the pendulum can be damped by a *resisting torque M_R* produced by two types of forces: a *viscous force* produced by a *magnet* faced to the disk (the eddy currents due

to the relative motion of the disk-magnet produce a resisting torque proportional to the angular velocity $M_R = -\gamma\omega$, or a constant resisting torque (sliding friction) produced by a soft brush touching the disk $M_R = -A\ \mathrm{sign}(\omega)$.
- The *intensity* of friction torque can be varied by adjusting the position of the magnet or brush.
- The *effective length* of the pendulum can also be changed by sliding the ball along the rod.
- Finally, the *mass* value *M* can be *modified* by changing the type of rubber ball.

We developed an application for Android/IOS based on the *PhyPhox* application, freely downloadable on web. This allows to obtain immediately plots of the pendulum motion as shown in Fig. 2. The application allows few manipulations of the acquired data: *Zoom*, and *Selection* of two acquired points (for which *linear interpolation* is drawn. For more datahandling the user must use external data analysis (e.g. Excel) using the option "*Export this data set*" to copy the data file into a PC (e.g. via DropBox).

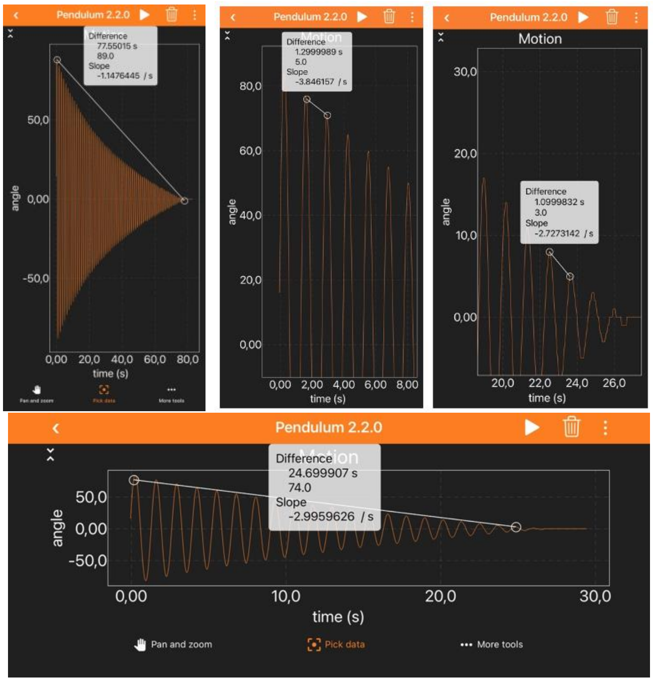

Fig. 2 Viscous-damped (top) and friction-damped (bottom) oscillations

An example of representation of three data sets (acquired with free pendulum, magnetically braked and with sliding friction) is the following

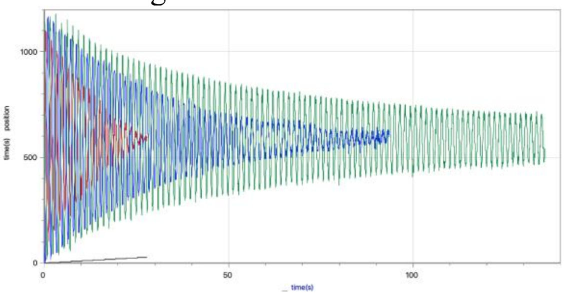
Fig. 3 Three type of damping compared

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Oral presentation 2 (#4, subtopic B)

Using a 3D Camera and a Local Positioning System in Physics Instruction

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Abstract. We are exploring the use of two new tools for hands-on physics instruction. Both tools allow us to investigate position-based phenomena more freely than traditional instructional equipment. The Pozyx local positioning system uses ultra-wideband radio frequency for localization. Beyond position measurement, the device provides pressure, acceleration, rotation, and magnetic field data. The Intel RealSense D435i camera allows positioning in 3D using two infrared cameras, an infrared emitter, and a colour camera. We are investigating how the devices can be used to study position and motion-based phenomena in lab and classroom activities that could not be tracked easily with other equipment

Overview

Unlike typical physics education equipment using infrared or ultrasound, the Pozyx (https://www.pozyx.io) device enables tracking of an object without the need of reflecting light or sound from a surface. This allows more flexible tracking of objects. The Pozyx local position system uses ultra-wideband wireless radio frequency for localisation. Depending on the setup, the positioning of a tag can be done in 1D, 2D, or 3D space. For 1D ranging at a data rate of up to 200 Hz, two Pozyx devices communicate with each other to get the distance between the devices to an accuracy of about +/- 10 cm. For 2D and 3D positioning at data rates up to 30 Hz, four or more devices serve as anchors (similar to satellites in GPS) and multiple tags can be tracked with respect to the known location of the anchors. In addition to the position, the tags have pressure sensors, 3-axis accelerometers, gyroscopes, and compasses.

There are many examples of how videos are used in physics education to track objects in real-time or with post-processing (e.g. references (Mylott, 2014), (Widenhorn, AJP 2016), and (Widenhorn, TPT 2016)). However, there are some limitations as motion must be in one plane and is distorted for certain camera angles and locations of the tracked objects. The systems presented here, do not suffer from the same constraints and expand the type of experiments that can be analysed. We have found the Pozyx system is ideal for tracking objects in a large space like a classroom, gym, or outdoor sport field; while the Intel RealSense D435i (https://www.intelrealsense.com/depth-camera-d435i) is useful for tracking objects in a more confined space with one setup requiring the use of only parts of a classroom. Both have the capability of real-time data observation but have limitations regarding their spatial resolution and data rate. We expect both limitations to decrease with future improvements as new devices are available to educators.

The Intel RealSense D435i camera outputs 3D position data by utilising stereo vision. The most precise data with a depth accuracy of about 1.5% is found for low gloss surfaces between 0.2 and 2.0 meters away from the camera. The camera is capable of tracking objects using colour at a resolution of 1280x720 pixels at 60 frames per second (fps) when post-processing the data or at 30 fps in real-time. We developed a colour tracking and graphing program that can record, graph, and determine trend lines of position, velocity, acceleration, and momentum of multiple objects in the scene.

Sample activities

Modelling, one of the six focus areas in the AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum, is the development of abstract representations of real systems, allowing for the creation of predictions, determination of limitations, and exploration of uncertainty relevant to the system of study (Kozminski, 2014). Through the investigation of air drag in "free" fall experiments using the Pozyx system, students receive an introduction to modelling systems through the analysis of air resistance (Siebert, EJP 2019). In a vertical launch of a projectile, we use the Pozyx device to measure the pressure at different altitudes and track the flip and swing of the projectile on its downward path using the accelerometer, gyroscope, and magnetic field sensors (Siebert, TPT 2019). Studies have shown that students who receive graphical representations of motion in real-time achieved the greatest learning gain (Duijzer, 2019). In this vain, we have created a set of kinesthetic learning activities where students act out kinematic graphs in both 1D and 2D space while the Pozyx devices records and graphs the position data in real-time (DeStefano, 2019) and (Dale, 2020). Additionally, the Pozyx device can be used with other devices. In a Tug of War activity, the Pozyx device was combined with a load gauge through an Arduino device (DeStefano, 2020).

For 3D motion, the Intel RealSense camera is a useful substitute for traditional teaching equipment. One such example is studying the motion of two balls colliding in the air. The objective of the collision activity is for students to review their current understanding of mechanics while analysing the momentum of the centre of mass as a function of time along all three coordinate axes. Our next step in utilising the 3D camera is to use existing skeletal tracking software to analyse the angular and translational motion of joints relative to other joints, such as a wrist relative to an elbow joint as a person throws a ball. The intended users will be high school and college level pre-health students in introductory physics courses. Student learning will be measured in the future using standard assessment tools like the FCI or FMCE.

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Oral presentation 3 (#7, subtopic A)

WebEJS: A fully Web-Based Version of Easy JavaScript Simulations

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Abstract. We introduce a new implementation of Easy Javascript Simulations. WebEJS uses a client-server architecture to help create JavaScript simulations on any Internet-enabled device, without any additional software. The client uses Internet standards, so that it runs on computers and tablets, storing files in a user's cloud account. The WebEJS server provides the power to edit and produce a stand-alone, independent of WebEJS, JavaScript simulation. The server runs as a Docker container, easily installable on standard computers. This client-server combination is a sophisticated, user-friendly use of technologies that results in a platform easy to install and use by teachers and students.

Introduction

EJS, at that time called Easy Java Simulations, started as a Java program to help physics teachers create Java simulations for educational purposes [1] and soon evolved into a successful tool used by teachers and students worldwide. The tool was also included as part of the OpenSource Physics project and, as such, has received several international awards [2]. Its author also received the MPTL 2015 Excellence Award for this work.

With time, EJS added a JavaScript version, which still runs on Java, but it is now able to create Internet-ready simulations based on JavaScript, HTML and CSS. However, the tool requires a Java virtual machine to run and, therefore, can only be run on a computer.

This limitation and the fact that Java new versions are making it more and more difficult to maintain the original program running, lead the authors into a long-desired project, developing a purely Internet-based version of EJS.

WebEJS

We introduce a new implementation of the successful modelling tool EJS in its JavaScript variant. WebEJS uses a client-server architecture to help create JavaScript simulations on any Internet-enabled device, without any additional software. The client uses Internet standards, so that it can be run on computers and tablets alike. This WebEJS client stores the user's JavaScript simulations in a user's cloud account, such as Dropbox. The client can also import EJS simulations from the AAPT-ComPADRE digital library.

The WebEJS server provides the power to edit and produce a stand-alone JavaScript simulation in zip format that is independent of EJS. The server is distributed as a Docker container (a fully self-contained package of everything needed), easy to install on standard computer platforms. This client-server combination is a sophisticated but user-friendly use of Internet technologies that results in a platform easy to install and use by teachers and students.

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Oral presentation 4 (#14, subtopic C)

Implementing Virtual Instruments to Increase Knowledge Comprehension and Engagement Rate in Distance Physics Teaching

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Abstract. Distance learning is becoming more and more popular nowadays due to increased mobility, widespread distance work, and the recent pandemic situation. Since it is a relatively new trend, teachers must actively adapt the methods and curriculum in order to suit modern needs. Like in any novel industry, there are several challenges to overcome such as a higher rate of destruction, comparatively limited possibilities to present the information, a decrease in discipline, and a lower engagement level. During my practice of distance teaching Physics to secondary school students, I tried to overcome aforecited challenges by incorporating modern technologies in my online lessons.

Introduction

It was always difficult to keep students active and interested in the material during the lessons and stimulated teachers to come up with new methods and ideas on how to involve students in the learning process even more, such as active learning, learner-centered approach, inquiry-based learning, etc. The rapid widespread of distance learning forced teachers to adapt those methods furthermore. One of the biggest challenges in teaching Physics online I have faced is not having the possibility to show experiments and the lesson, in general, is less engaging. It's more difficult to influence the students in order to encourage them to do homework and work independently. Studying from the comfort of own home cannot provide needed stimulus like when a student physically goes to school.

There are also lots of negative influences on students' attention span – the amount of time one is able to actively concentrate on the task [1, 2]. Fatigue, hunger, noise, and emotional stress significantly reduce attention span. Furthermore, since distance learning keeps students glued to their devices, there is a great problem of constant destruction by social media [3]. It is believed that social media in general deteriorate the learning process and shorten the attention span and memory retention ability [4]. One of the ways to increase attention span is to keep students engaged.

In order to increase the information comprehension level and decrease the destruction, I start working with students by agreeing on classroom rules, such as having cameras on, phones should be turned off or put away, and copybooks and pens being a must. Anyway, exceptions are possible, for example, in case if a student has no functioning camera, but nowadays it is extremely rare. During the presentation of new information, it is vital to keep students aware, so I am asking them different questions to estimate something or make an assumption based on the theory. Therewith, the lesson is always divided into chanks for not more than 10 minutes of similar activity. This requires wide variety of activities prepared upfront to be able to diversify the lesson.

One of the formats to be included in the lesson is to use virtual simulations such as those shown in fig. 1. There are virtual laboratories on different topics, such as Electricity, Magnetism, Atomic structure, etc. I have developed two main ways of incorporating those virtual laboratories in my work based on the level of the student, including prior knowledge and concepts assessment and dealing with misconceptions.

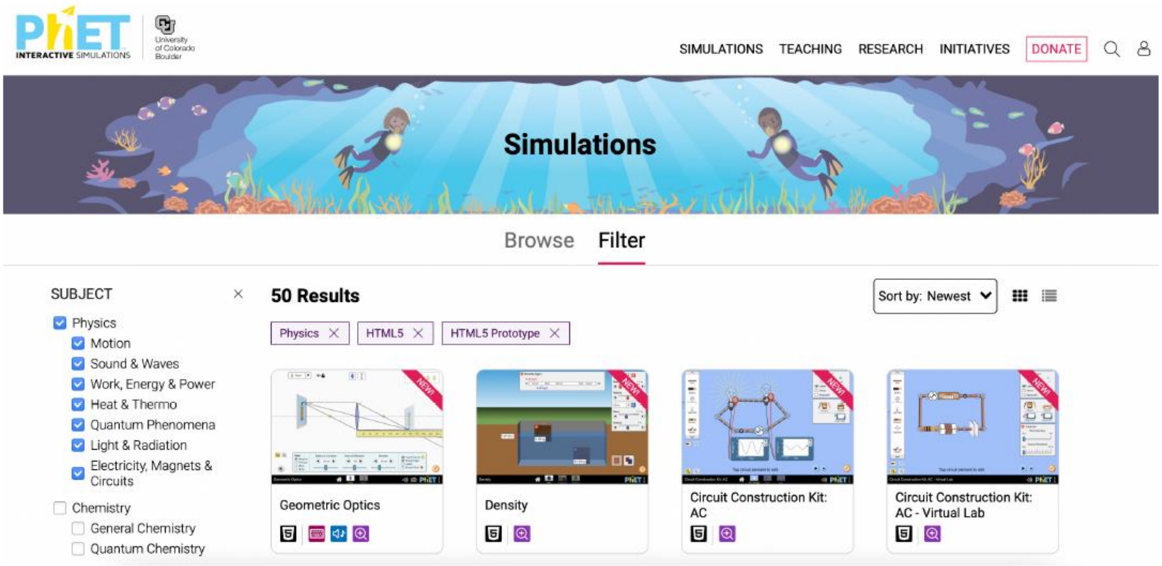

Fig. 1. An example of virtual laboratory simulations.

Virtual laboratories make a great combination with further interactive tools such as those for the autonomous work of students. They can practice individually or in a group on a laboratory activity and prepare a presentation about their work.

In general, I find it very profitable to include modern tools in the learning process. It keeps students interested in the process and puts the teacher closer to them like a person, who keeps it with the times.

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Oral presentation 5 (#15, subtopic A)

Visualization and Metacognitive Scaffolding in Learning from Animations about the Anomaly of Water

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Abstract. In a series of two experiments, we examined the influence of metacognitive scaffolding and supplantation on students' learning performance during self-regulated learning with animations about the anomaly of water. A static and a dynamic visualization format with respect to learning success was tested. We provided metacognitive scaffolding by means of cognitive and metacognitive prompts during the learning sequence. Results suggest that static visualization of system transitions are superior to dynamic visualization of animations in the science classroom while metacognitive scaffolding was not helpful in these short time, linear learning sequences.

Introduction: Learning with Animations in Science Classrooms

With regard to learning with of animations, there is huge body of research comparing static and dynamic visualizations. Nevertheless, findings of these studies still show inconsistent or inconclusive findings regarding the benefit of animation on learning [1]. Animations and simulations are dynamic visualisation techniques that have been widely used especially in science education because here learners often have to deal with complex concepts and processes. Animations are often used to dynamically represent "structure, causality and/or chronology" of process flows, both in real processes (e.g., reformulation of equations) as well as in abstract processes (e.g., formation of antibodies or ecdysis of snakes)[2]. Therefore, animations are important educational resources which support science teaching and learning. When designed appropriately, interactive media can contribute to overcome misconceptions in science. A major advantage of animations is the provision of a dynamic visualization of transitions between a specific content's different phases and stages. In that sense, film and animations can support mental operations due to their external representation and can contribute to supplantation [3].

Supporting Self-Regulated Learning with Digital Representations

When using animations (and other instructional media like textbooks, simulations, etc.) it is important to consider students' abilities in self-directed learning. Self-regulatory competences can be seen as an important key factor in successful learning processes in general and specifically when using digital resources [4]. An approach to enhance the effectiveness of self-directed learning with instructional media is to apply additional instructional strategies. An example of such a strategy is the provision of (meta-)cognitive scaffolding [4]. The research questions within this research addressed the question, whether the kind of animation (static vs. dynamic system transitions) can contribute better or worse in understanding the molecular structure of water with regard to water anomaly. In addition, we examined the impact of metacognitive scaffolding during learning with the animations.

Method

An animation about the behaviour of water molecules and their super-ordinate structures that depend on temperature has been developed. The animation itself functioned as visual metaphor for what happens with the molecules at certain temperatures. A square surrounding the molecules was displayed to visualize the ratio of molecules and the volume. In addition, density and temperature were displayed at the left side of the animation. Results from the first study revealed that this visualization was too complex. Thus, in a second experiment a modified version was used (see Fig. 1). The independent variable visualization was operationalized in two different ways: In the dynamic condition, the molecules in the animation moved between different temperatures and built superordinate structures in a dynamic manner. For the static condition, images were displayed sequentially without transitions. Both versions had the same auditory explaining text.

Metacognitive prompting was operationalized by providing five metacognitive prompts in total. These prompts consisted of brief written instructions provided by a pedagogical agent and related to the respective learning content. Participants were given a paper sheet where they had to make their notes regarding the task presented in the overall five prompts while pausing the animation. Results from a first experiment revealed here that the number of prompts provided a high cognitive load. Thus, in a second experiment only one at the beginning and one at the end were used so that participants did not have to pause the animation.

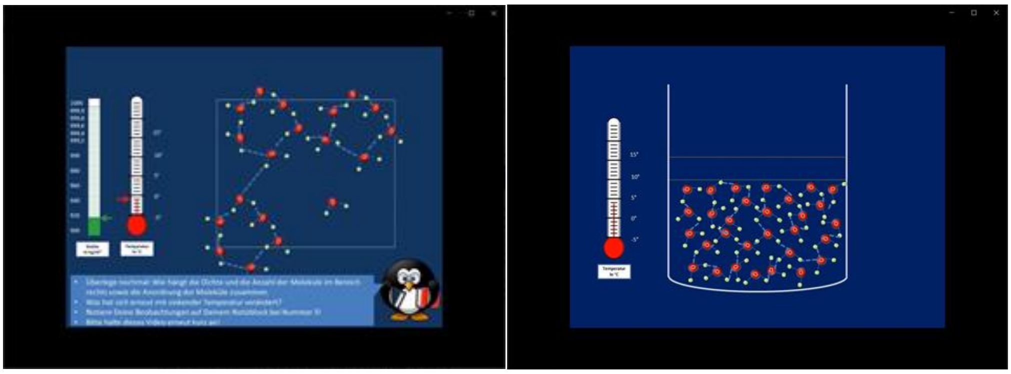

Fig. 1. Animation with scaffolding (left) and the modified version without scaffolding (right).

Findings and Conclusions

Results from both experiments showed that that the static visualization of system transitions of different states of water molecules were superior to dynamic visualization of animations. In addition, metacognitive scaffolding did not support learning here but rather increased cognitive load of learners. Results imply that metacognitive scaffolding might be helpful in complex and long-term learning environments, but not in short time, linear learning sequences as provided here. In addition, findings support evidence that dynamic animations are rather effective when learning content is challenging and contains spatiotemporal information. For the chosen domain here this seems not to be applicable which explains the benefit of static visualizations.

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Oral presentation 6 (#17, subtopic A)

Students' Perspective on the Classroom Response Systems in Physics Classrooms

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Abstract. We have used the online feedback app Mentimeter as an example of a Classroom Response System in different teaching environments and have investigated student opinions on the effectiveness of using them in physics teaching environments. We find that, generally, students find Mentimeter useful in creating an active learning environment, generating interest, involvement in teaching, and providing a formative assessment of their understanding. Many students find it difficult to speak up in class and we find it is an effective way for students to participate in classroom discussion without having to overcome this barrier. Many students would welcome more frequent and more general use of applications such as Mentimeter in large classroom settings.

Introduction

Large university classes are usually seen as a disadvantage by both students and lecturers. We usually see minimal contact between students and the lecturers in such classes. Students often feel "lost in the crowd." Teachers encounter low motivation and minimal student involvement with the material [1]. Although students taking these courses often do reasonably well on traditional exams, numerous studies demonstrated a shallowness in their understanding [2]. Enabling interaction in a large class seems an impossible task for lots of faculty members. Multiple studies showed that with increased engagement, students may be more likely to attend classes [3].

An effective tool to help this interaction is the Classroom Response Systems (CRS). The CRS is a set of hardware and software that facilitates teaching activities such as posing questions to students via an overhead or computer projector and receiving their response using a handheld transmitter (a *clicker*). However, in the newer versions of the CRSs, like Catalytics, Mentimeter, Socrative, Poll Everywhere, and Kahoots, smartphones are acting as the handheld transmitter, and send data to a server using Wi-Fi signals. The CRS can be used for questioning, immediate response and display, and data analytics in a classroom [7].

In this research, Mentimeter was used in several teaching settings in two different universities, and students' opinion was gathered using online surveys during the last week of the classes. The first setting was the combined Physics courses for non-Physics students (Biomedical, Environmental, Food and Nutritional Sciences, Biological and Chemical Sciences), taught during the second semester of 2018-2019 in National University of Ireland, Cork (UCC). Around 370 students were enrolled in this course which consisted of 24 lectures. Mentimeter has been used as an example of Classroom Response Systems in this class, in to maximise students' engagement with the classroom and provide feedback to the instructor and students.

We have also used Mentimeter in first year Oscillations and Waves seminars, at Imperial College London during last 3 years. These seminars were held in a renovated lecture theatre specifically designed for active learning, with around 68 students in 13 groups. We have used Mentimeter not only for formative assessment, but also to collect experimental data from students to teach a new topic. We then asked students in both setting, about their perspective on the effectiveness of these tools. Only 3% of participants in UCC didn't find the Mentimeter App easy to use, and majority of student believe tools like Mentimeter should be used in all large Physics setting. As seen in Fig. 2, the number of participants in UCC who strongly agree or agree, that by using Mentimeter they were involved in learning during class, are 4 times more than the students who strongly disagree or disagree. They submitted similar results for the following questions

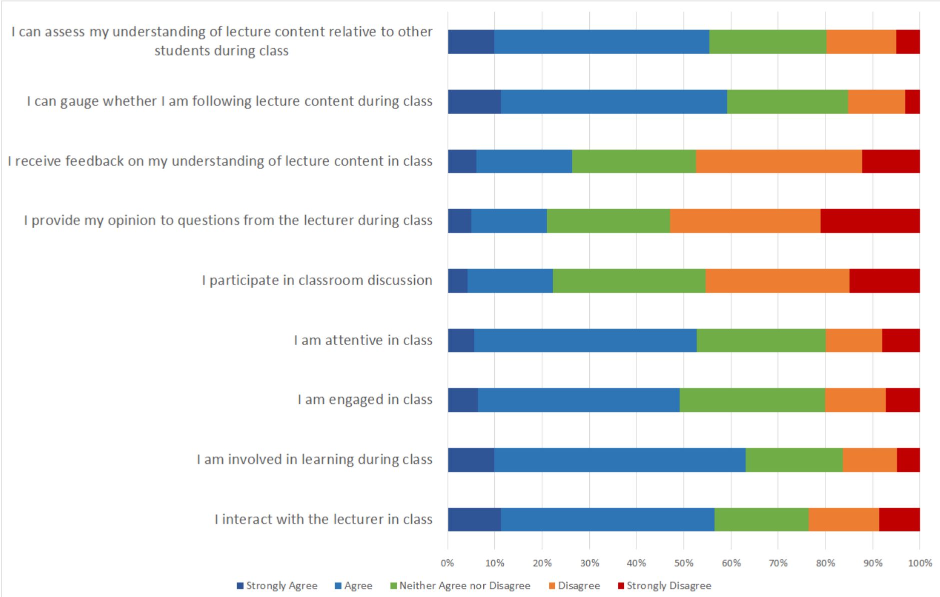

Figure 1. UCC Students responses, when we asked them "What did you get as a result of using Mentimeter?"

regarding Mentimeter: "I interact with the lecturer in class", "I am engaged in class", "I am attentive in class", "I can gauge whether I am following lecture content during class" and "I can assess my understanding of lecture content relative to other students during class". Around 47% of the participants said that Mentimeter didn't help them to participate in classroom discussions or to receive feedback on their understanding of lecture content in class.

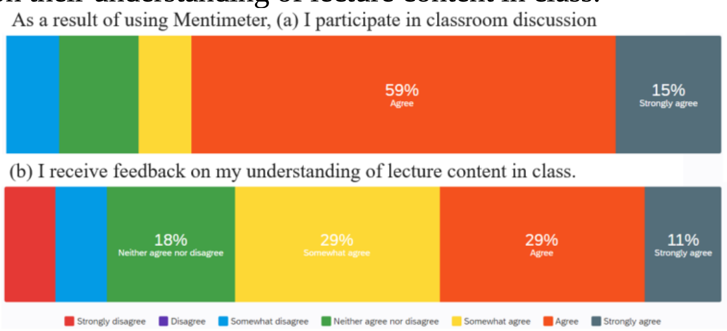

Figure 2. Imperial College Students opinion on using Mentimeter in the Physics seminars.

In the Physics seminars at Imperial, we gave more time to students to discuss the Mentimeter questions with their peers, before submitting their response. Similarly, students found the tool very useful to be involved and interact with the class these students As shown in Fig. 2, only 8% of these students said that Mentimeter didn't help them to participate in classroom discussions, and 14% of participants think Mentimeter didn't provide feedback on their understanding.

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Oral presentation 7 (#19, subtopic B)

Use of a Mobile Phone and Readily Available Objects for the Study of Oscillations and Internal Gravity Waves in a Stratified Fluid

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Abstract. We propose a variant of the well-known Cartesian Diver experiment, where the diver floats in a fluid stratified in density obtained from the dissolution over time of a quantity of coarse salt placed at the bottom of the container.

In contrast to the original version of the experiment, the diver can stop in a stable equilibrium position within the fluid, at the height where the surrounding density matches its own. By varying the applied pressure, the diver's density changes and it moves to a different height accordingly. When a sudden pressure pulse is applied, the diver, pushed off its temporary equilibrium position, starts oscillating due to a restoring force. The frequency of oscillation, known as Brunt–Väisälä frequency, depends on the density gradient. Therefore, by changing the pressure on the container, students can span different heights and density gradients and observe their evolution in time with a single non-invasive experiment. Other interesting phenomena occur, such as the propagation of internal gravity waves typical of stratified fluids when a portion of them is displaced transmitting its motion to the surrounding fluid. These phenomena typically occur in the atmosphere and in the stars and are difficult to visualise as they only produce refractive index variations within the fluid. One trick to make them visible is to put in suspension small fragments of a material of appropriate density, which localise in a fluid layer and oscillate when the gravity waves pass. Therefore, with this simple experiment that students can project and realise by themselves with easy-to-find objects and by following all the steps, it is possible to introduce them to complex phenomena of general interest.

Thanks to the use of a mobile phone and of simple free educational programs, which allow recording the diver oscillations, plotting and fitting the data, students can perform quantitative analysis of the results, and therefore enhance their understanding of the physics issues.

Oral presentation 8 (#21, subtopic B)

Simple experiments to observe and analyse Haidinger's brush with a smartphone

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Abstract. Optical polarisation phenomena are ubiquitous in physics, chemistry, biology, and engineering. Optical polarisation is best studied in an interdisciplinary approach that combines biology and technology, which usually makes it more interesting for students. The first glimpse of Haidinger's brush can be an exciting discovery for many students. Polarisation also has profound conceptual significance for the curriculum, and many nice polarisation experiments can be done with cheap materials.

Simple experiments to analyse Haidinger's Brush

In physics, chemistry and biology, a variety of optical phenomena occur that are based on the polarisation of light [1]. The study of optical polarisation in a school context or in undergraduate studies can be done particularly well with an interdisciplinary approach that combines biology, physics, chemistry, and technology. This can usually make the subject area more interesting for pupils and students [2]. The phenomenon of Haidinger's brush [3] is unconsciously observed by many people in everyday life – e.g. seen on a computer screen when the gaze falls back to the screen after having previously been averted from the screen – and possibly interpreted as an error in the display on the screen or as a brief irritation of the eyes, as the phenomenon disappears again after a short time and is no longer visible without a movement of the head. An investigation of Haidinger's brush can be an exciting discovery for many students and motivate deeper discussion of optical polarisation. In addition, polarisation also has profound conceptual significance for curricula, and many nice polarisation experiments can be done with inexpensive materials. This contribution presents experiments that students can perform using a smartphone as a source of polarised light and the naked eye as an analyser.

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Oral presentation 9 (#20, subtopic C)

What happens when a tube made of paper hits a surface?

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Abstract. Computer is a powerful tool which can be comprehensively used for scientific and educational purposes. Using a tool that can register videoclip and program for video analysis (e.g. Tracker) one can investigate the motion of almost every object. Taking advantages of multimedia it is also possible to determine many physical properties of the objects - among others motion track, elasticity coefficient. The paper presents preliminary results of investigation of a paper tube motion. Methods, findings and conclusions are under discussion.

The case of falling tube

A paper tube (also called a muf or a thin-walled pipe), initially raised above and inclined at a certain angle to the horizontal, begins to move in a translational motion when dropped from a certain height [1]. The cause of movement is the force of gravity of the Earth, while the force of air resistance has a braking effect. Then, as a result of the collision of a part of the lower edge of the tube with a flat surface, the tube is additionally set into a rotary motion around an axis passing through the center of the body mass. The final position of the tube is determined by a number of initial conditions and properties of the system and leeds to two different stages presented in the figure 1.

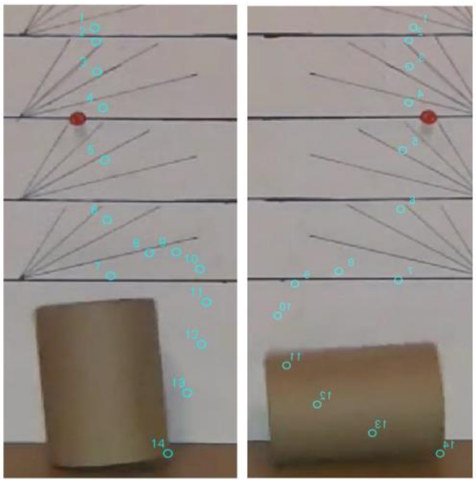

Figure 1. Final position of a falling tube – vertical (on the left) and horizontal (on the right).

Investigation of the tube's properties performed with use of multimedia technology and correlating the findings with the behaviour of the tube gives interesting results and conclusions which are forming the essence of a presentation.

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Poster 1 (#8, subtopic C)

Teaching Introductory Physics Interactively Using Videos and Simulations in a Personalized Learning Platform

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Abstract. We summarise the creation and early results of introductory physics courses at Portland State University (PSU) with an emphasis on active and interactive features such as videos and simulations to enhance student learning. The course is designed to support student learning with conceptual questions, scaffolded homework, and simulations where students can use activities to explore the concepts. Videos are included to present the content along with text pages for students to choose from per their learning preferences. Videos were also created using experts in different disciplines such as biology and medicine for students to recognise the relevance of physics to those disciplines.

Introduction

Over the past four years, as part of a university-wide initiative to introduce personised learning at PSU, we have developed calculus-based (https://www.cogbooks.com/physics-calc) courses using the adaptive learning platform CogBooks. Since 2018, these courses have been taught in-person and due to the Covid pandemic also in an online format by four different faculty members at PSU. Other institutions have adopted our CogBooks courses as well, but we currently do not have data on those implementations. At PSU, physics majors take the calculus-based course, but the largest student groups taking the courses are engineering students (calculus-based) and pre-health students (algebra-based courses with or without pre-health focus).

The curricular materials include videos that can be used as pre-lectures or instead of in-class lectures. Videos present physics concepts, walk students through problem-solving, experimentally demonstrate physics phenomena, and provide background information. Some videos are taken from external sources like https://bozemanscience.com and https://dontmemorise.com, while other videos on problem-solving and pre-health background were produced by us (for more information on the on the pre-health relevant physics curriculum see for example Mylott et al. (Mylott, 2016). A collection of our pre-health physics videos can be found on our Youtube channel (https://www.youtube.com/user/PhysicsinBiomedicine). We provide additional free curricular resource for instructors on the Living Physics Portal (https://www.livingphysicsportal.org). Similarly, the homework assignments frequently include simulations that are either taken from freely accessible sources (e.g. https://phet.colorado.edu) or designed by us (https://www.geogebra.org/u/portlandstate). The texts are either authored by us or adapted from free sources like the Openstax (https://openstax.org) textbooks in physics or anatomy & physiology. The curricular materials are set up in a learning path that allows students with a solid grasp of the material to spend less time on concepts they have a good handle on. Along the main learning path, students can take advantage of extra problem-solving exercises, videos, or text with support on physics concepts allowing students to personalise their learning. With increasing use, the CogBooks environment is designed to be adaptive and learn from the students' interaction with the system.

Goals

The course is designed to engage students with different learning preferences and needs by incorporating active and interactive features (Freeman, 2014). While initially designed for an in-person course as shown in Fig.1, the platform is flexible to allow different implementations. This was particularly helpful when the pandemic forced us to switch between in-person, online, and hybrid instruction. The price for accessing the course materials ($30 for each of the three terms) represented a significant decrease in cost to our students. Though not many students needed it, instead of the traditional textbook, students could use the Openstax books as an additional resource. For all courses, we had a particular emphasis on teaching students how to problem solve in physics. For the pre-health course, we also wanted to increase students' engagement by connecting the physics content to biomedically relevant topics.

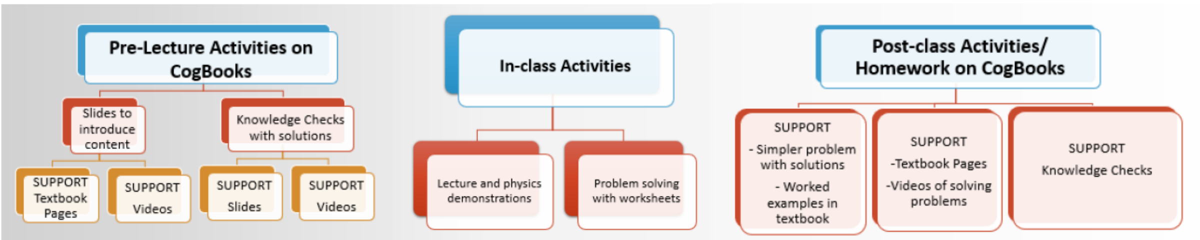

Figure 1. Course structure of the in-person implementation of the course.

Advantages of the course design include:

- Content, interactive simulations & assessments on the same platform
- Support items (worked examples, videos, detailed content, math review) are provided
- Students can work at their own pace and choose their learning path
- The platform supports in-class as well as out of class learning

Assessment

We are assessing the impact of the courses using various means. Log data is analysed to study the engagement of students with the system and improve the course content. Student surveys are used to assess student attitudes about the courses. For the pre-health focussed course, we focus specifically on how the biomedical content impacts student engagement and drew from assessments like the Colorado Learning Attitudes about Science Survey. Engagement is also studied in more detail using student interviews at the end of this year's full-year course sequence. Physics questions from standard assessment tools (e.g., Force Concept Inventory, Force and Motion Conceptual Evaluation, and Brief Electricity and Magnetism Assessment) and questions we have put together to match the learning goals for the courses are included in exams or in-class activities to assess physics content learning. The university's enrolment system is used to measure the impact of the courses on minority student groups and first-generation college students.

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Poster 2 (#9, subtopic A)

Improving Student Problem Solving with Interactive Online Tutorials

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Abstract. We have developed a set of 30 Interactive Video-Enhanced Tutorials (IVETs) designed to help students learn effective problem-solving strategies. The IVETs incorporate multimedia learning principles, are adaptive and guide students through an expert-like problem solving strategy while providing different levels of feedback and guidance for different students. They also adapt to students' affect by providing additional guidance to students who indicate they are confused, frustrated, or bored while completing the IVETs. This presentation will showcase the IVETs and present research results from implementing them in large-enrolment physics courses.

Introduction

While there are many products and strategies for delivering active instruction [1], there is a need for online research-based materials that support problem solving in physics. To address this we created a set of 30 Interactive Video-Enhanced Tutorials (IVETs) [2] that span the topics of a year-long introductory physics course. We tested ten of them to see how their educational effectiveness compares to that of passive video instruction.

Theoretical framework

Even students who have learned problem-solving techniques often have not developed the necessary strategies for applying this knowledge [3]. Research indicates that mastery is developed through *deliberate practice* [4]. This involves completing many effortful activities with feedback specifically designed to improve the level of performance, explicitly highlighting how decisions are made for using specific principles, concepts, and procedures [5]. Deliberate practice in an IVET includes supporting students with guidance and targeted feedback throughout the entire problem-solving process [6]. Another important part of the IVET design is the application of multimedia learning principles [7] that are based on research in human learning and memory. For example, students are given control over the pace and mode of presentation (either text or video), which motivates students' engagement and impacts learning [8].

IVET design

IVETs are web-based, self-paced, and short, often taking less than ten minutes to complete. Each is focused on a challenging introductory-physics problem that exemplifies an important concept or principle. They include videos of mini-lectures interspersed with multiple-choice or multiple-select questions, where students must choose the correct answer before moving to the next video segment. Feedback is provided whenever an answer is chosen (either correct or incorrect). The questions and feedback are designed to carefully step students through each stage of an expert-like problem-solving process, while emphasizing the reasoning behind each step. Students who require less guidance can navigate through quickly by selecting text instead of video for the questions and feedback, while students who need more support can choose video summaries that provide extra guidance. Most IVETs are also affect-adaptive, meaning that students are asked how they feel midway through the activity and are then given targeted feedback to encourage and help them if they are struggling.

We developed the *Vignette Studio II* application for authoring IVETS, Interactive Online Lectures and similar assignments. It is available on the project website https://ivet.rit.edu.

Methods and findings

For each of the 10 IVETs that we studied, the IVET was assigned as homework to one section of a physics course, while another section was assigned to watch a passive video solution of the problem. In the passive video the narrator talked through the same problem-solving process and explicitly emphasized key decisions but without the interactive questions. Students in both sections had covered the topic in class, but neither had used these principles concurrently in the same problem. During class after treatment, students were given a follow-up problem to complete individually for a grade, allowing us to compare interactive video (the IVET) with passive video.

As an example, for the Torque and Rotation IVET the quiz scores were put into three groups: Those who completed the IVET (N=73, average score 51%), those who watched the control video (N=66, average score 40%), and those who did not complete either treatment (N=61, average score 32%). A one-way ANOVA yielded a statistically significant difference in the quiz scores for all three groups ($p < 0.05$) with a marginal large effect ($\eta^2 = 0.11$; suggesting 11% of the variance in scores was due to treatment type). The IVET group performed significantly better ($p < 0.001$) than the no treatment group, as well as the video group ($p = 0.013$). Details for this and other tests will be shown in the presentation.

Conclusion

IVETs are relatively effective at teaching problem solving in physics. The IVETs and their authoring application may be downloaded from https://ivet.rit.edu at no cost. (Supported by National Science Foundation grants DUE-1821391 and DUE-1821396.)

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Poster 3 (#13, subtopic B)

The Difference between Total and Inexact Differential Using 3D Printing Technology and LEGO© Bricks: Application on the First Law of Thermodynamics

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Abstract.
The poster presents two educational kits created with the help of 3D printing technology. Both kits are used as a part of the course of advanced thermodynamics aimed specially at future high school teachers. The kits deal with multivariable differential, emphasising the difference between total (exact) and inexact differential, and the First Law of Thermodynamics.

Why we need aids for these purposes

Understanding the meaning of the differential in the advanced course in thermodynamics is crucial, but also very difficult for the students. Because we teach a course specifically designed for future high school physics teachers, we consider understanding the meaning and building the geometric view to be more important than mastering calculations with differential. For this purpose we have developed specially designed tasks and various educational tools that help us reach our goals. Use of 3D printing technology enables us to show complex concepts with excellent precision. Moreover, by manipulating tangible objects, we try to engage students' touch with their sight, hearing, and thinking. Such an approach is beneficial for studying the given topic as well as for enrichment of their pool of didactic methods.

Technology

We decided to work with functions of two variables because the third dimension can be used for visualizing the functional value and such functions are very common in thermodynamics (e.g. temperature as a function of volume and pressure). Technology of 3D print has enabled the production of prisms with precisely inclined surfaces, which would have been very difficult to manufacture manually.

The first educational set shows the differences between total and inexact differential. It consists of two sets of 25 chamfered blocks with a square base (see fig. 1). The inclination of the upper base of green blocks corresponds to the total differential $\mathrm{d}F = y\,\mathrm{d}x + x\,\mathrm{d}y$ (it corresponds to the function $F(x, y) = xy$). The slope of the upper bases of the red blocks set corresponds to the inexact differential $đG = y\,\mathrm{d}x - x\,\mathrm{d}y$ (such function G does not exist). The blocks are placed on sliding bars, so it is possible to clearly demonstrate the meaning of differential $\mathrm{d}F$, resp. $đG$ and calculation of the curve integral by changing the height of the blocks.

The second educational kit is based on the laws of a single atom ideal gas. It consists of three sets of 49 chamfered blocks (see fig. 2), which represent the differentials of internal energy (total differential), heat and work (both inexact differentials). The lower sides of blocks fit into Lego© cubes and baseplates, that's why we do not need to create a special construction or print many other cubes for "line integration". Moreover, we tuned the slope of the upper surfaces, so that the integration increment “between the two cubes” corresponds to a multiple of the height of the thinnest Lego cube. The whole set thus enables quantitative considerations and numerical verification of the first law of thermodynamics.

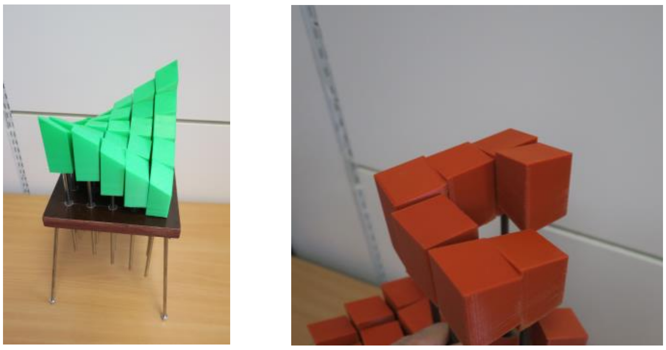

Fig. 1. The first kit – total differential assembled as a function of two variables (left), the line integral along the closed curve of the inexact differential (right).

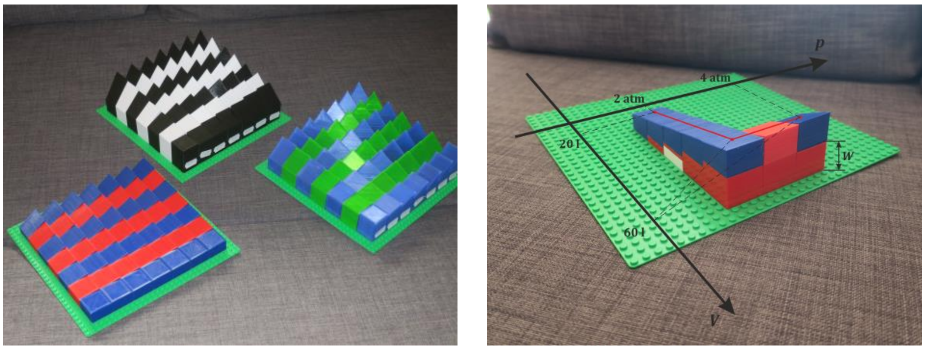

Fig. 2. The second kit. In the left: Three differentials of one atomic gas on the left photo (work has red and blue blocks, internal energy has light blue and green blocks, heat has black and white blocks. In the right: Work of ideal gas in the isobaric and isochoric process on the right photo.

Teaching experience

We have been using the first educational set as a lecture demonstration tool for six years (one of them in distance learning). According to both the students’ opinion and their results in solving problems, the understanding of the meaning of multivariable functions’ differential increased significantly, as well as understanding the differences between total and inexact differential. Usage of this educational set creates a geometric view of differential that serves as a base for following discussions about the differential of real physical quantities later in the course.

We used the second educational kit once in distance learning (the lecture demonstrated ideal gas properties) and last year we piloted its usage in standard educational setting (i.e. in a classroom). Students used the kit independently and solved assigned tasks with its aid. These tasks allowed them not only to explore the mathematical properties of differentials, but also to understand that the First Law of Thermodynamics is not only the law of energy conservation.

Summary

The use of 3D printing enabled the creation of visual educational kits showing the mathematical and physical significance of the differential, including emphasizing the difference between total and inexact differentials. The first one is more suitable as demonstration tool during the explanation of the basic ideas of the topic. The second one is accompanied by assignments for independent student work, so it can be used for deeper hand-on exploration. The long-term impact on student understanding will be a subject of further research.