Methods and technological tools to support active learning at school and university

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Abstract. Active learning experiences can be significantly enhanced by the use of appropriate methods and technological tools. Interactive videos, collaborative learning platforms, interactive simulations, real-time data collection and analysis tools, modeling environments, adaptive learning technologies, and learning management systems are all examples of tools that can promote engagement, collaboration, and personalized learning. By incorporating these tools into their teaching, educators can create more engaging and effective learning experiences for their students. In this symposium, the use of some of the aforementioned tools in an active-learning environment and the necessary planning of pedagogical activities based on them will be discussed.

Introduction to the Symposium

Active learning is a student-centered educational approach that encourages students to take an active role in their learning process. The pedagogical methods related to this approach are credited with improving student conceptual understanding in many fields, including physics [e.g., 1-2]. Instead of passively absorbing information from the teacher, students are encouraged to engage with course material, ask questions, and apply what they learn to real-world scenarios. Consequentially, critical thinking, problem-solving, and collaboration are promoted and students can assume responsibility for their own education.

In recent years, technological tools have been used to enhance active learning methods and experiences, providing new ways to promote engagement and facilitate the construction of knowledge and skills. These tools can help students engage with course material, collaborate with their peers, and personalize their learning experiences. By incorporating these tools into their teaching, educators can create a more engaging and interactive learning environment that can lead to better scholastic/academic outcomes.

Among the many technological tools available for educational purposes, interactive videos, collaborative learning platforms, interactive simulations, real-time data collection and analysis tools, modeling environments, adaptive learning technologies, and learning management systems have been used to foster active learning in students. In this symposium the use in an active-learning environment of some of the abovementioned tools will be discussed. Particularly, we will concentrate on the use in inquiry/investigative-based learning environments at both school and university levels of:

1. interactive simulations, where students can modify relevant parameters of the simulation and observe the results in real-time;
2. real-time data collection and analysis tools implemented with computers, Arduino-type systems and smartphones;

3. laboratory tools aimed at promoting experimental skills and developing expert-like attitudes toward experiments.

The four contributions to this symposium will not only describe the use of these tools, but will also discuss the necessity to meticulously plan the structure of pedagogical activities and school/university courses based on them. Only then will students be able to not only perform hands-on activities, but also reflect on what they are doing and develop reasoning skills centered on the explanation of observed situations and conducted experiments.

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Learning actively in an undergraduate physics laboratory course: From deep foundations to experimental skills acquisition

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Abstract. The introductory laboratory course at the University of Potsdam has been redesigned with the goal to engage students actively in experimentation and foster acquisition of experimental skills. In the transformation process, we defined learning goals, then developed activities to reach a specific set of these goals, and assessed the achievement of those goals based on students' learning. The results of the assessment were used to revise the course activities and goals iteratively. I will present examples of newly designed, seminar-like and laboratory activities, describe the course scaffolding used to support students, and discuss the assessment of the course transformation.

Introduction

Teaching approaches that engage students in actively and collaboratively constructing their knowledge have been found to be more efficient than approaches in which students are just passively receiving information. A guide to the literature in this field can be found in [1]. Physics laboratory courses (PLCs) could be considered to be intrinsically "active learning" environments, but recent research studies have questioned the effectiveness of traditional prescriptive PLCs to improve physics content knowledge [2], experimental skills [3, 4] and students' views and attitudes towards experimental physics [5]. New "active learning" teaching approaches in PLCs have been proposed [3, 6, 7]. Based on these findings, we have redesigned our PLC for physics major students at the University of Potsdam (UP) from a traditional "teacher-focused" and "concept-based" type into a "students-centered" and "skill-based" type of course in which students engage actively and collaboratively in learning activities. I will present the process and assessment of our course redesign.

The "active learning" PLC at the University of Potsdam

Before our transformation, the main goals of the PLC were to reinforce physics concepts and passively teach several types of measurement methods and data analysis techniques. The teachers pre-installed and pre-optimized laboratory experiments, and students followed detailed instructions on data-taking and analysis. As reported in the literature, we found that students' engagement was low, and the acquisition of experimental skills was missing in this setting. Following the model proposed by Zwickl et al. [8] for transforming a PLC, we defined two course learning goals. First, students should acquire experimental skills like modeling, design, and communication. Second, students should understand the nature of experimental physics and develop expert-like attitudes toward experiments.

To reach those goals, we carefully redesigned the course structure with frames to let students' abilities grow systematically. We created new teaching materials and activities and offered students targeted support from instructors. We make use of authentic forms of laboratory notebooks [9], the modeling framework for experimental physics [6], and rubrics [3]. We encourage students to make decisions while designing experimental setups and procedures, while doing the data analysis, and to reflect on those decisions. To make students feel confident in taking decisions and efficiently practice a particular skill, we designed special "active learning seminars".

We have established this for the fundamentals of data analysis and scientific documentation. We furthermore initiated laboratory activities to foster specific experimental skills. For example, to foster the modeling of a physical system, students receive a closed box containing an unknown electrical element (either resistor, capacitance or inductance) and typical laboratory equipment for electrical measurements with the task to find out which element is inside the box. To foster the modeling of measurement systems, students characterize the limits and non-ideal characteristics of different measurements instruments and sensors for Arduino microcontroller.

To assess students' learning during our course transformation, we used the Colorado Learning Attitudes about Science Survey for Experimental Physics (E-CLASS) [10]. We recently translated it into German and created an automated centralized system that allows instructors of German speaking countries to assess their courses [11]. We found a positive, statistically significant shift of students' attitudes and views towards "expert-like" thinking. The largest positive shifts are observed for items regarding students' confidence in taking decisions and overcoming difficulties independently. However, our findings show that the aspects that we did not specifically address in the laboratory course can degenerate to "novel-like" views.

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Active learning in the light of current neurosciences illustrated by the use of a force sensor in a hand of a pupil

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Abstract. In the contribution, we discuss two taxonomies of active learning and illustrate them on some teaching-learning sequences related to using a force sensor. We illustrate active learning in demonstrations and teaching-leaning activities in which pupils have a force sensor in their hands and minds. The activities we try to arrange in a sequence, where we discuss some results of the learning sciences, including neuroscience, and model a design of part of the physics curriculum for the age of 12-15. In the examples, digital technologies are utilised, especially data gathering and presentation of the data in the form of a value and a graph.

1. Introduction

Last decades, if we discuss learning, one of the first few associations is active learning or deep learning. For both, the relevance of the content and types of activities is crucial. In active learning, pupils are engaged in the lessons (synchronous parts of the courses) as well as in the homework (asynchronous part of the courses). For learning to be active, we can find at least two taxonomies. In a strict taxonomy, activity is referred to as doing something physically [1] (e.g., manipulating with real apparatus, changing a power source voltage, manipulating with a slider in a computer model). In a wider use of this word, the pupil can be active also in watching a static chessboard (selecting from possible movements with a chess piece, or watching a video sequence of a physics experiment. Being active in learning, in this contribution, means doing something physically, e.g., look, gaze, or fixate, underline or highlight, gesture or point, paraphrase, manipulate objects, select, repeat, activate existing knowledge, assimilate, encode, or store new information, search existing knowledge [1]. Generally, we can use the term active learning to represent learning in learner-centred activities compared to passive participation in content delivery in teacher-centred education. Interesting findings were recently published by Buchan et al. [2]. They unexpectedly found, on the topic of evolution, that the teacher-focused scheme was the most successful in part owing to a replicable interaction effect but also because it enabled engagement. These results highlight the importance of testing lessons in a sequence and indicate that there are many routes to effective engagement with no "one-size fits all" solution in education [2].

In this contribution, we present a series of teaching-learning sequences, activities, where a force sensor in a hand of a pupil (one pupil of a team of pupils) can have a crucial role in fulfilling the goals of physics education. Although it is obvious that the concept of force is one of the essential concepts of physics, we can document this truth through the work of W. Harlen [3]. W. Harlen with her team identified 10 Big Ideas of science, ideas which they recommend to be reached at the end of compulsory schooling. The third of the big ideas is directly related to the concept of force, "Changing the movement of an object requires a net force to be acting on it". Some relevance has the concept of force also in the second big idea, "Objects can affect other objects at a distance", and the fourth big idea, "The total amount of energy in the Universe is always the same, but energy can be transformed when things change or are made to happen."

To present an active approach to the development of the concept of force and other concepts related to the concept of force, we try to apply well-known ideas that pupils learn better when they are scaffolded and when they work with data gathered by themselves (as teams of pupils), and within interleaved education [4]. So, we present a model of curriculum design, parts related to the use of force sensors, at the age of 12-15.

2. Force sensor at the ages of 12-13, 13-14, 14-15

The principles and other ideas of active learning from the view of neurosciences illustrate on the use of force sensors, in various ways, at different stages of physics education. We start at the age of 12, and build on the experience pupils usually have from lower grades and/or from common life, e.g., in a kitchen where they use kitchen scales. We do not cite any national curriculum; rather, we address theoretical possibilities and model a new curriculum design. In some parts of the curriculum, we mention the application of the design process to the design of the physics curriculum in Slovakia.

Some implication for teacher training to foster active learning with a force sensor with casuistic

This contribution also discusses some aspects of in-service teacher training to foster active learning with a force sensor. As the most difficult, we see activities where pupils should actively propose an experiment (or at least measurement). Teachers in Slovakia were not trained to foster experiments planned by pupils, and most of them say that it is difficult to engage all pupils working on different activities. In one example, pupils decided to measure the maximal force a thread can stand. In another example, pupils decided to measure the time variation of force exerted on a floor when a pupil does a squat. In the third example, a group of pupils examine the force necessary to keep a cart at rest on a slope.

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Some ISLE-based teaching-learning sequences as good practices of active learning

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Abstract. A case study of active learning based on the Investigative Science Learning Environment (ISLE) is presented. In this pilot lab format the iOLab digital devices have been adopted as a multi-purpose, easy to use equipment to acquire and analyse data taken in various simple, yet significant experiments. The effectiveness of this approach is discussed and put in comparison with more traditional teaching-learning strategies.

Introduction to Active Learning in the laboratory

The introduction of active learning strategies is important in both physics lectures classrooms and in laboratory courses. Despite lab activities could be seen as interactive as students engage with various equipment and each other in group work, recent research indicates that traditional confirmation-style labs, at first year undergraduate level, characterized by step-by-step instructions and pre-determined outcomes, are ineffective in terms of both content learning and development of lab skills, as well as in fostering positive student attitudes towards laboratory work [1,2]. Possible intervention strategies thus involve reducing the detailed instruction to be given to students to leave room for their decision-making and limiting the confirmatory aspects of lab activities. A review of various approaches employed by physics lab instructors in lab courses can be found in [3].

In the field of Physics Education Research (PER), various lab course curricula have been developed, such as the RealTime Physics (RTP), SCALE -UP (Student-Centred Active Learning for Undergraduate Programs) and ISLE (Investigative Science Learning Environment), each possessing its own unique features.

Among the above formats, we rely in this work particularly on ISLE developed by Etkina and collaborators ([4] and references within). ISLE is a comprehensive approach that engages students in a cycle of learning that mimics the way professional physicists proceed. In ISLE based courses, students work in groups to formulate explanations for phenomena proposed and carefully chosen by teachers, then create experiments to verify their explanations.

Additionally, the advent of new hand-on technologies such as apps to manage smartphone sensors, Arduino microprocessors, devices with sensors and a graphical user interface such as iOLab developed by the PER group at University of Illinois [5] can provide educational support in teaching fundamentals of data analysis and active learning. Students can work at home with their device, which remains the same during all activities, thus also reducing cognitive load for each student. An example of implementation of active learning strategies with Arduino and smartphone at first year university level can be found in [6].

In this communication we describe labs modelled after the ISLE approach, through the use of devices with sensors, for high school and undergraduate students as well as for high school physics teachers with the aim of introducing them to a modern and stimulating strategy.

Lab learning sequences: structure and pedagogy

The ISLE- style laboratory activities take place over 4-6 hours, in sessions over 2 or 3 weeks and involve the use of devices such as iOLab or smartphones. Students initially answer a questionnaire intended to characterize their approach to the laboratory. In the first lesson of each sequence, the device is introduced and students are asked to take simple measurements to become familiar with it.

The experiments were proposed as observational, testing or application experiments in 11th or 12th grades classrooms. Students worked in small groups with worksheets in which they reported their observations and conclusions about the phenomena to be analysed. In one of the sequences, devoted to sound and acoustics, students used also a Jupyter Notebook in Python as an interactive tool to learn the FFT amplitude spectrum and its use as an additional graphical representation [7]. At the end of every sequence, they were given a questionnaire on their perception of the activities and some specific questions to assess the effectiveness of learning. Other sequences to be proposed in 13th grade, consider the magnetic field and some elements of modern physics with LEDs.

Table 1: The sequences of labs

Sequences	**Lab activities**
Mechanics: applications of Newton's laws	Dynamic friction; Atwood machine; circular motion; harmonic motion
Mechanical waves and sound	Frequency of a sound; FFT amplitude spectrum of the sound recorded with a microphone; frequencies in a DTMF signal; acoustical standing waves in a tube
Electric field and DC circuits	Relationship between electric potential and electric field; studying a circuit with a light bulb or an LED; Ohm's law

Conclusions

In this communication we describe some pilot lab format sequences carried out with high school classrooms in a ISLE framework and based on digital devices as iOLab and smartphone. Although the interventions were of short duration, it was observed in almost all classes that students succeeded in using the device fruitfully. On the other hand, as an indication, it emerged that in general students are not used to an inquiry-based approach to laboratory activities, and neither to comparing and testing the models studied on paper as exercises and problems with experimental activities.

In this workshop we will show the results of a more quantitative analysis, including the interventions in 2022-2023, that can be useful as a basis for designing reformed courses of broader duration over several years.

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Simulation activities of surface phenomena in liquids: an innovative approach based on a mesoscopic model

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Abstract. In this contribution we discuss an educational approach based on modelling and simulation activities of surface phenomena in liquids. The approach aims to promote student use of lines of reasoning useful to explain proposed or observed surface phenomena. We outline a model of liquid based on a mesoscopic approach and examples of computer simulations students can use during the activities. Preliminary results of the analysis of student answers to a questionnaire before and after instruction and of other qualitative data show that these activities can help the students to think in terms of "mechanisms of functioning".

Introduction

In recent decades, model-based methods of physics instruction and learning have gained popularity in the academic literature. (e.g., [1]). According to studies, the inclusion of modelling activities in physics classes can foster a positive attitude toward learning physics, enhance students' comprehension of the subject [2], and improve students' epistemological beliefs [3] about models and their use in learning science [4]. Moreover, a teaching strategy that emphasizes modelling can improve students' reasoning by assisting them in recognizing similarities among a variety of phenomena that, upon initial inspection, may appear dissimilar [5].
As reported by Rutten et al. [6], an effective way to introduce students to modelling is to engage them in collaboratively use interactive simulations that allow them to actively modify some parameters of the models and discuss the consequent effects in real time.
In this contribution, we focus on the advantages offered by modelling and interactive computer simulation activities in promoting student use of lines of reasoning [1] useful to explain proposed or observed surface phenomena. The choice of the surface phenomena as a topic was driven by the consideration that the foundations and applications of this topic are relevant to many scientific and technical fields, like physics, engineering, medicine, and environmental sciences. Moreover, surface phenomena are often perceived by students, and even teachers, as obscure and not so relevant for educative purposes, also at university level [8].
After a discussion on the physical aspects of a mesoscopic model of liquids [9], we present relevant examples of computer-based simulations we implemented by using the model and Smoothed-Particle Hydrodynamics (SPH) computational method [10], and we discuss the aspects of a structured educational path on modelling and simulation of surface phenomena.

Modelling and simulation activities

The modelling and simulation activities are based on a mesoscopic model of liquids. Students are initially introduced to the model without discussing mathematical details of the SPH method. Students are only required to understand the types of interactions between particles by discussing the pressure force and the molecular like force. Particularly, they focused on the different role played by forces over small and large distances and on different interaction between two "liquid" particles and "solid" and "liquid" particles. By using numeric simulations based on the SPH method, students are able to control relevant model parameters and compare the results of the simulations with the experimental results. Students are encouraged to use the computer tools to

manipulate the main quantities of models and to visualize the simulation results. They actively discussed and compared the results collected by the various groups.
By using the simulations, students are able to study different surface phenomena, manly qualitatively and, in some cases, also quantitatively. The primary objective is to enable students to comprehend, at least qualitatively, that the sources of these phenomena are particle interactions, by visualizing (also by making movies by means of the simulation software) the main forces acting on each particle. Students can modify the interaction intensity between couple of particles and observe the effects of these changes both on the mechanical equilibrium reached by the studied system and on the temporal evolution. For instance, students can study the rise of a liquid in a capillary tube. They can modify the values of interaction intensity and gravitational acceleration and observe how these changes affected the liquid level reached along the capillary tube and meniscus curvature radii which are formed inside the capillary tube and outside in the vessel. In this case, students can also estimate the capillary length for this system.

Discussion and Conclusions

Our preliminary results show that allowing students (and teachers) to control relevant physical parameters in a simulation, can enhance the understanding of the ways in which knowledge is constructed and improving students' reasoning. Particularly, it can improve the understanding of the mechanism of functioning at the basis of phenomena that are observed or studied. Further studies are necessary to better correlate the typical quantities of the model with the macroscopic ones in the specific case of surface phenomena, so to allow students to also explain complex situations, related to real-life situations and so particularly relevant for them.

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