Insights and Reflections in Physics Teaching and Learning at High School and University

Online Symposium. Organized by GTG Physics education Research at University-PERU
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Abstract. Many countries are experiencing significant problems with engaging students with the advanced study of physical sciences. Where this is the case, it is a source of significant concern. Whilst science and engineering are often seen as interesting to young people, such interest is not reflected in the learning outcomes in science and engineering degrees that have little success in the early years. The reasons for this are complex but need to be addressed. More attempts at innovative curricula and ways of organising the teaching of science that address the issue of low student motivation and learning are required. This Symposium presents emerging topics in physics teaching and / or learning as an effort to innovate and improve the research-based physics education.

Presentation of Symposium

The science and engineering degrees are undergoing changes in the physics curriculum with the goal of enhancing student learning and interest in learning physics. In addition, the COVID-19 pandemic has caused that universities to have had to suddenly switch to electronic teaching. Teachers had to modify their courses to an e-teaching environment and introduce online teaching strategies. Often these innovations present changes based on the results of research in physics teaching, but they must be evaluated for their effectiveness. Those innovations in the curriculum that develop learning through the practice of scientific skills in specific contexts must evaluate their results and establish their strengths and weaknesses.

The Symposium presents four research-based innovations. Two of them focused on innovations in two important aspects of physics teaching, problem solving and laboratory work. The other two proposals deal with innovations related to the teaching changes that teachers have had to make due to the COVID-19 pandemic and online teaching. E. Sijmkens, T. De Laet and M. De Cock dealing with helping students in problem solving strategies. They will present a prototype for an online tool that aims at stimulating students' metacognitive skills for problem solving by offering them problem-specific reflection questions. P. van Kampen & O. Gkioka Will present an investigation on the criteria used by first and second year university students to judge the quality of experimental measures of two covariant quantities that do not exactly follow a simple relationship. They analyze the extent to which they use measurement uncertainty to guide their decisions. T. J. Kelly will talk about specific initiatives hat due to the COVID-19 pandemic, we undertook to design and implement practical teaching activities using basic, home-built apparatuses that could be used to explore key concepts in instrument design, systems modelling, and control systems. A group of physics education researchers from Germany, Austria and Croatia, L.Ivanjek, P. Klein, M.-A. Geyer, S. Küchemann, K. Jelicic, A.Susac, will present project to evaluate teaching and learning processes during COVID-19 pandemic in the context of physics courses at the university level. Report. They will show preliminary results concerning students perception on synchronous and asynchronous physics lessons, their self-organization skills, activities and teaching methods they perceived as helpful.

A Disciplinary Learning Companion

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Abstract. Problem solving is an important aspect of physics education. To become skilled problem solvers students do not only need sufficient conceptual and procedural knowledge, but they also need metacognitive skills in order to monitor their solution process. We present a prototype for an online tool that aims at stimulating students' metacognitive skills for problem solving by offering them problem-specific reflection questions. We discuss a case study of the implementation of the tool within a 1st year mechanics course.

1 Introduction

Problem solving is an important aspect of physics education. To become skilled problem solvers, students do not only need sufficient conceptual and procedural knowledge, but they also need self-regulated learning skills. Intervention studies have shown that self-regulation is associated with academic achievement and as such, it is important to support the development of students' self-regulation. Although 'self-regulated learning' is a widely used term, different theoretical models highlight or include different aspects: some of the models focus on metacognition while others also include elements of affect and motivation.

In this contribution, we report on the design and preliminary evaluation of a prototype for an online tool that aims at stimulating students' metacognitive skills for solving mechanics problems. The tool is inspired by the recently developed Learning Companion. This Learning Companion, introduced by Tormey et al. [1], is carefully grounded in theory and designed to promote self-regulation while students solve engineering problems. It presents students with a standard questionnaire for each problem including a predefined list of generic difficulties related to quantitative problem solving. Ample scientific research has, however, indicated that metacognition is more effective when it takes place in a domain-specific context. Moreover, developing particular conceptual knowledge in mechanics is difficult and requires particular attention. Therefore, the goal of our research is to determine the feasibility and impact of a "Disciplinary Learning Companion" (DLC), building on topic-specific questions rather than generic questions to trigger reflection with students during or after problem solving in the context of mechanics.

2 Disciplinary Learning Companion

The goal of the Disciplinary Learning Companion is to make students reflect on problems they are typically solving in the context of a higher-education science course. It is a self-reflection tool that students use independently during or after they solved a single problem or set of problems, and that presents problem-specific questions and feedback to trigger the students' reflection. Based on research on problem solving [2, 3] we identified five key dimensions to structure the reflection questions: 1) Strategy Plan, focusing on the use of a well-considered strategy to tackle the problem; 2) Concepts, focusing on the domain-specific concepts needed to solve the problem (e.g., developing a free-body diagram in mechanics); 3) Mathematical model, i.e., translating concepts to mathematical formulas (e.g. equilibrium of forces); 4) Computations, i.e., solving the mathematical model obtained; and 5) Interpretation, i.e., interpreting and evaluating the obtained solution (e.g., are the magnitude, sign, and units of my solution as expected?).

The design of the Disciplinary Learning Companion is based on Flavell's ideas on metacognition [4, 5]. According to Flavell, metacognition is students' knowledge about their processes of cognition and the ability to control and monitor those processes as a function of the feedback received via outcomes of learning. He discriminates between metacognitive knowledge and metacognitive skills that include planning, monitoring, evaluating and controlling.

3 Design and implementation of the Disciplinary Learning Companion

The design and implementation of the DLC was done in the context of an introductory physics course for first year bio-engineering students (N ~ 300. The course consists of two 1,5-hour lectures and one 2-hour problem solving session each week and mainly deals with mechanics. We designed reflection modules based on the problem solving sessions: each week we provided students with an extra problem (and solution) they could solve and reflect on (based on the tool) as a preparation for the next session. The online tool allowed to study how students deal with the modules. Moreover, we administered the MSLQ questionnaire [6] as a pre- and post-test to measure students' use of (metacognitive) learning strategies in order to study the connection between students' interaction with the tool and the evolution of their metacognitive abilities. Furthermore, we analysed student responses to a final exam question in order to study the effect of the modules. We consider their achievement on this exam question and whether they had a well-considered strategy to tackle the exam problem. Preliminary results show that only a fraction of the students do take part in the reflection tool consistently which makes it difficult to measure the impact. Detailed results will be presented.

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Student judgement of the quality of covarying data

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Abstract. In undergraduate labs students often obtain experimental measurements of two covarying quantities that do not exactly follow a simple relationship. We have investigated what criteria first-year and second-year university students use to judge the quality of this kind of data, and to what extent they use uncertainty in the measurement to guide their decisions. To this end we analysed student responses to open response questions. We have also studied what actions students propose to increase the trustworthiness of the covarying data or a conclusion based on the data.

1 Introduction

Our work is heavily influenced by the research on student understanding of measurement of a single variable carried out in collaboration between the Universities of York and Cape Town [1-5]. In their research they analysed the responses to written questions that focused on decisions to be made regarding data collected for a single quantity (often a length). They arrived at a framework for interpreting students' reasoning characterized as "point", "set", and "mixed" paradigms to classify students' actions and reasoning. "Point" reasoning is governed by the underlying belief that each measurement provides a single value which could be the "true" value, and that the uncertainty associated with the measurement of a particular quantity could, in principle, be zero. "Set" reasoning is underpinned by the belief that each measurement is an approximation to the "true" value with a non-zero uncertainty, and is part of a set of measurements that collectively gives information on the variable. Many students appeared to "mix" point and set reasoning, for example by using data analysis procedures consistent with set reasoning (e.g. calculating the mean) but giving interpretations consistent with point reasoning (e.g. not considering the spread).
Early work identified that high school students' reactions to covarying data depends on both their expectations and the trend apparent in the data [6,7]. Volkwyn *et al* [8] looked at students' interpretation of graphical data scattered around an implied straight line, and interpreted join-the-dots graphs as consistent with point reasoning, straight line graphs through a number of data points as mixed reasoning, and best-fit lines as consistent with set reasoning. More recently, a 10-item closed-response instrument called the Physics Lab Inventory of Critical thinking (PLIC) was developed to probe students' understanding of uncertainty in structured way [9].

2 Findings

The questions we gave to our students were quite open-ended. The questions presented a data set with a number of outliers and asked students whether they trusted the data and how they would use the data to derive a quantity, or whether they agreed with a conclusion based on the data and if not, what they would suggest instead [10]. The contexts were simple and familiar enough that students could reasonably be expected to know or infer a theoretical relationship between the variables, but the relationships were not given. Neither were any hints given that they could use uncertainty in the data as a criterion. In doing so, we tried to mimic a real

laboratory situation in which they had completed a set of measurements, and had to consider what to do next.
We found that students considered factors independent from the actual values of the data (such as agreement with theory or expectation or controlling variables), the quality of the raw data (e.g. whether the outliers were acceptable to them or not), and quality of the derived quantity (e.g. whether each pair of data points provided roughly the same value for the derived quantity). Students proposed either to improve the data in different ways (e.g. with better equipment, greater care) or to use the data set with provisos (e.g. to only use "good" data points). To find a derived quantity from covarying data, our students proposed to calculate the mean, use individual data points, or use a best fit line. They used the spread in the data, if at all, to judge the quality of the data in an ad hoc manner; they did not see it as an essential part of the measurement. Those who (spontaneously) drew best fit lines appear to use it to eliminate outliers rather than to determine a mean for the derived quantity.

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Hands-On, Minds-On at home activities for teaching systems modelling and control systems in a college level physics programme.

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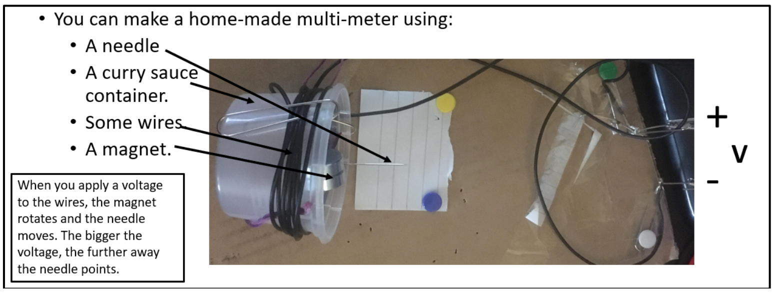
Abstract. At the Galway-Mayo Institute of Technology, we teach a degree programme in Physics and Instrumentation. The aim of the course is to equip students with a hands-on working knowledge of the applied physics concepts that underlie the instruments and engineering systems that are used in industries common to our geographical area, the west coast of the Republic of Ireland. Due to this, our degree programme tends to be delivered with over 60% contact time through hands-on practical laboratory teaching. Thus, there was a significant challenge when the COVID-19 pandemic hit in continuing to deliver teaching in this way. In this talk, I will talk about specific initiatives we undertook to design and implement practical teaching activities using basic, home-built apparatuses that could be used to explore key concepts in instrument design, systems modelling, and control systems.

1. Introduction

Dealing with the transition to online teaching was particularly problematic for degree courses with a heavy emphasis in laboratory teaching. In some cases, the exercises and teaching activities traditionally delivered could be adapted into a *virtual* setting using online simulations or by replacing experimental activities with computational exercises. In some other cases, costs permitting, equipment could be shipped out to students' homes and supervision could be provided remotely through Zoom or MS Teams. In other cases, at home activities that were still experimental in nature but relied on home-built instruments and activities were used. Home-built activities have some advantages over other activities that include a potential lowering of the extraneous cognitive load that could occur when "lab-grade" equipment is sent to a students' home. Similarly, 'lab-grade' equipment is often of a quality where the sensitivity, accuracy, precision, and linearity results in a global experimental error far below what would meaningfully affect a students' ability to make a measurement. Therefore, as part of some modules I was teaching, I decided to ask students to construct home-made experimental equipment that could showcase concepts related to instrumentation, systems modelling, and control systems. These activities included: Using sewing needle, magnet, and paper cup as a makeshift galvanometer; A hair dryer and 'shrink-paper' to model a first-order system step response; and a magnet, elastic bands, and a coil of wire to show-case the impulse response of a second-order system.
The students were tasked with preparing and carrying out an experimental investigation of their choosing after receiving a lecture on that topic. For example, after a lecture on 2nd order system characterisation, some students decided to investigate how the impulse response of a spring-damper system changes with the elasticity of the system. Student response to the activities were overall positive, submission rates were higher than the departmental average, and the over all pass-rate for the course was higher than in previous years.

2. Instrumentation Characterisation

A home-made galvanometer is constructed from the following equipment:

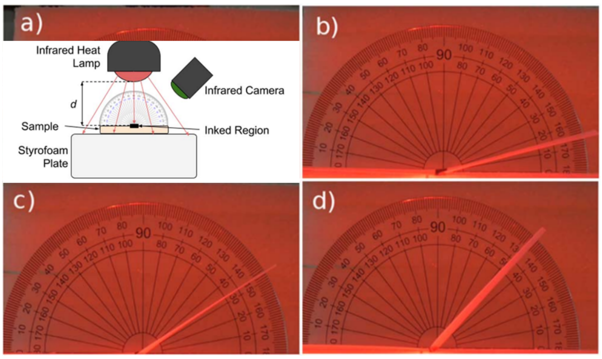


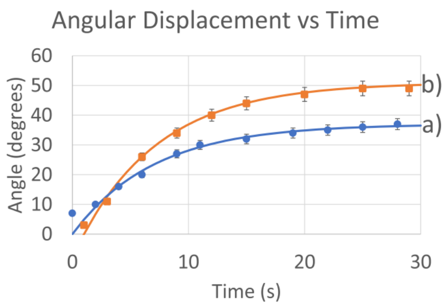
Students are encouraged to explore the following concepts of instrumentation:

- Linearity by exploring the needles linear deflection and angular deflection as a function of applied voltage.
- Sensitivity by exploring the change in needle position per change in voltage for different needle lengths.
- Accuracy by making marks at known voltage deflections and then tesing an unknown battery source.
- Precision, and resolution by using different linear scales to measure the needle deflection, or different thickness of needles.

Systems Modelling

A simple, but effective demonstration of the step response of a first order system can be found by exposing a visco-elastic material to a heat source (such as a hair dryer).





Figuur 1 The children's toy 'shrink-paper' is explosed to a heat source. The subsequency deflection of the paper is modelled as a fisrt order response [1].

The response of this 'shrink-paper' to a heat source is modelled as a Maxwellian visco-elastic matereial whose stress-strain relationship has the form $\sigma = E\varepsilon + \eta\frac{d\varepsilon}{dt}$. This can also be modelled in the Laplace domain with the Transfer Function $T(s) = \vartheta_0 \frac{\frac{\eta}{E}}{s+\frac{\eta}{E}}$.

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Teaching and learning physics at university level during the COVID-19 pandemic

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Abstract. In March 2020 COVID-19 pandemic has caused a sudden shift to e-learning at schools and universities worldwide. Most of these institutions were not prepared for this shift and were not offering online classes beforehand. A group of physics education researchers from Germany, Austria, and Croatia has started a joint project to evaluate teaching and learning processes during the COVID-19 pandemic in the context of physics courses at the university level. As a part of the research 18 semi-structured interviews were conducted, and a questionnaire was administered to 578 students from 5 universities. The results on students' perception of synchronous and asynchronous physics lessons during first COVID 19 lockdown, their self-organization skills, activities, and teaching methods they perceived as helpful and the implications for the future physics courses will be presented.

4 Introduction

COVID-19 pandemic has caused a shift to e-learning in the last three semesters at schools and universities worldwide. Although e-learning existed before and there is a body of research about it [1-3], most institutions were not prepared for this sudden shift and the students at those institutions did not voluntarily decide to take part in online courses but were forced into an e-learning setting through COVID-19. This situation opened an opportunity to assess and compare different formats of online teaching. A group of physics education researchers from University of Vienna, Austria, University of Zagreb, Croatia, TU Dresden, University of Göttingen and TU Kaiserslautern, Germany has started a joint research project to evaluate teaching and learning processes during the COVID-19 pandemic in the context of physics courses at the university level.

In this contribution, we report on the preliminary results of the study concerning students' perception of synchronous and asynchronous physics lessons, their self-organization skills, activities, and teaching methods they perceived as helpful, and on their wishes for the future physics courses. In particular, three research questions will be answered: (1) Which course formats during unexpected e-learning situation did the students prefer and why? (2) Which course elements did the students find helpful for their learning? and (3) What are the implications for the future – what can we learn from this situation, and which online formats do students want to preserve even after the COVID-19 pandemic?

5 Methods

As a part of the research, 18 semi-structured interviews were conducted with 16 physics students and 2 engineering students from University of Vienna, Austria, University of Zagreb, Croatia, TU Dresden, University of Göttingen and TU Kaiserslautern, Germany, and the questionnaire with 246 technical data fields divided into 13 subtopics was administered to 578 students from these universities at the end of the summer term 2020. The questionnaire topics included general information about tools used for e-learning, demographic data, self-organization skills (general and during COVID-19 semester), environment, attitudes to synchronous and asynchronous teaching, helpfulness of different course activities, attitudes toward online learning, communication, expected learning achievement in the physics courses and implication for the future courses. Three additional subtopics concerned different course formats like tutorials, physics labs, labs for future physics teachers, and school practice. The interviews lasted for 33 - 94 minutes, were transcribed and analyzed using the framework of qualitative content analysis by Kuckartz [4]. The questionnaire was developed based on the results from interviews and literature review, and it was validated using a confirmatory factor analysis [5].

6 Preliminary results

The students' perception of synchronous and asynchronous course elements was assessed through interviews and the questionnaire. The results indicate that more students prefer synchronous courses and that they see more advantages for synchronous courses. These include the possibility to immediately ask questions, the feeling of community, and the fixed day structure. As a main advantage of asynchronous course formats, students mentioned the flexible time management and the possibility to learn at their own pace.

Students were also asked which course elements they find helpful. Face-to-face lectures at the university were considered most helpful from the students in our study, followed by recorded lecture videos and group work.

Concerning the implications for future physics courses, most of the students in our study would like to have uploaded course materials on the learning platforms and recorded lecture videos also available in the future. More detailed results of the study, including the correlations between preference for synchronous courses with other scales will be presented in the talk.

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