Rosenheim
Technical University
of Applied Sciences

PTEE 2024

12th Physics Teaching in Engineering Education Conference

TH Rosenheim, 15-17 May

Facilitating Student Learning
in a Changing World

THE PROCEEDINGS

SEFI
European Society for Engineering Education
Europäische Gesellschaft für Ingenieur-Ausbildung
Société Européenne pour la Formation des Ingénieurs

THE 12TH INTERNATIONAL CONFERENCE ON PHYSICS TEACHING IN ENGINEERING EDUCATION PTEE 2024

15-17 May 2024

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Keynote of Mieke de Cock on YouTube: "The Role of Mathematics in Understanding Physics | Mieke De Cock"

Keynote of Peter Riegler on YouTube: "Decoding the Disciplines - Understanding & Overcoming Students' Barriers to Learning | Peter Riegler"

PTEE 2024 REVIEW

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CONTENT

Editorial 3

Wim Bouwman and Jacob Hoogenboom
DIVERSIFICATION IN PHYSICS TEACHING BY TRANSFORMING PANDEMIC-ERA LEARNING THROUGH OPEN INTERACTIVE TEXTBOOKS 5

Tina A. Fuhrmann
WHAT I WISH I HAD KNOWN … WHEN I STARTED (ACTIVATING) TEACHING IN PHYSICS 9

Todd Gelbord
MOMENTECH - MODERN EXPLORATIONS OF THE IMPULSE-MOMENTUM THEOREM 18

Christian Hettich, Jürgen Sum and Bernd Jödicke
LEARNING THE PROCESS OF GAINING SCIENTIFIC KNOWLEDGE 26

Bernd Jödicke, Jürgen Sum and Christian Hettich
LEARNING PHYSICS METHODS IS IT POSSIBLE TO TEACH METHODS INSTEAD OF PHYSICS CONTENT? 31

Christian Kautz and Tina A. Fuhrmann
USING RESEARCH-BASED INSTRUCTIONAL MATERIALS TO FOSTER CONCEPTUAL UNDERSTANDING – *TUTORIALS* IN INTRODUCTORY PHYSICS 38

Julia L. Neff and Georg Krocker
RETHINKING CLASSICAL MECHANICS FOR ENGINEERING UNDERGRADUATES: A HANDS-ON APPROACH TO OSCILLATIONS AND WAVES 47

Jeroen B. Oostinga
LITHOGRAPHY CHALLENGES FOR PHYSICS AND ENGINEERING STUDENTS TO BECOME COMPETENT, SKILLFUL MICROTECHNOLOGISTS FOR THE SEMICONDUCTOR INDUSTRY 54

Tim Ruhe
FLIPPED CLASSROOM IN TEACHER EDUCATION 62

Tim Ruhe, David Düser and Andreas Karl Peter Schneider
THE QUANTUM MECHANICS VENUE – A TRANSFORMATION TO A CROSS REALITY LEARNING-TEACHING LAB 70

Sami Suhonen
NAVIGATING THE AI ERA: ANALYZING THE IMPACT OF ARTIFICIAL INTELLIGENCE ON LEARNING AND TEACHING ENGINEERING PHYSICS 76

Sami Suhonen and Juho Tiili
THE ROLE OF LEARNING SPACE IN ENHANCING ACTIVE LEARNING: INTRODUCING THE STEM-CENTER AT TAMPERE UNIVERSITY OF APPLIED SCIENCES 84

Juho Tiili
A NEW MODEL TO REALIZE PHYSICS TEACHING IN TAMPERE UNIVERSITY OF APPLIED SCIENCES 91

Martin Versen and Stefan Kipfelsberger
AN APPLIED EXAMINATION FORMAT FOR MEASUREMENT TECHNOLOGIES 96

Michael Wendlandt
THE LECTURE OF THE FUTURE: IS FLEXIBILITY IN TERMS OF TIME AND SPACE AT THE EXPENSE OF LEARNING SUCCESS? 102

EDITORIAL

Dear readers and dear participants of 12th PTEE conference,

Physics Teaching in Engineering Education conferences (PTEE) are international, scientific conferences each organized by a hosting university and the Special Interest Group of Physics (SIG) of the European Society for Engineering Education (SEFI). In addition to scientific exchange on teaching and learning in physics they offer an opportunity to meet peer, to discuss current issues, to learn from each other, to share experiences and to envision collaboration in the European countries.

At the 11th PTEE conference in Tampere, Finland in 2022, we were impressed by the warm hospitality of our Finish colleagues. So we agreed on bringing PTEE to Rosenheim hoping to be able to return some of this friendship to the participants. We believe that coming together to a European conference is maybe more important than ever. By meeting and working together we strengthen the international spirit in science and education.

Facing enormous challenges from international conflicts, or on top the climate change as well as opportunities for example from artificial intelligence, we live in a continuously changing world. And we are aware that this should have impact on our teaching or rather on how to facilitate student learning. That's why we chose "Facilitating Student Learning in a Changing World" as a motto for this year's conference.

On the PTEE conference 2024 in Rosenheim 80 participants from 14 different countries were able to experience an intensive and impressive program with three keynotes, four workshops, 32 oral contributions and 12 posters.

Mieke de Cock from KU Leuven (Belgium) gave exciting insights into student reasoning in her keynote from the field of Physics Education Research "The intimate relation between math and physics – beautiful for physicists, hard for students". She stated, that "as a physicist, we speak a mathematical dialect" and she could give the participants an impression, why this is difficult for students.

Decoding the disciplines is an in-depth method for analyzing student difficulties by conducting decoding interviews with experts. Peter Riegler (Bavarian Center for Innovative Teaching, Munich, Germany) showed in his interactive keynote "Decoding the Disciplines: identifying, understanding and overcoming students' barriers to learning and much more" examples, that help to gain a sense for the great potential of the decoding process.

Phyphox is an app that allows you to use your own mobile phone for physical measurements. The developer, Sebastian Staacks, from RWTH Aachen (Germany) demonstrated in his practical keynote classical educational experiments as well as further developments to combine the Phyphox App with Arduinos or other external sensors.

But in particular we were very pleased with the wide range of contributions to the conference. Many thanks to everyone who shared their ideas and experiences!

Additionally there has been an excursion to an institute with focus on applied building physics and visits of labs, active learning spaces and the astronomical observatory. Moreover we could enjoy Bavarian culture in a beer garden and a conference dinner on a Bavarian Alm in the mountains at 1400 m. Perfect weather – enough time for networking, exchanging ideas, envision future projects and socializing.

Now we are happy to announce that the next PTEE conference will be held in Warsaw, presumably in May 2026.

The Proceedings of the 12th PTEE conference 2024 in Rosenheim present 15 articles from a wide range of actual topics in physics teaching – from artificial intelligence, innovative teaching and examination methods, lab experiments, tutorials to thoughts on what would be desirable to know, when you start teaching (activating) physics. We hope you enjoy the reading!

Yours sincerely

Claudia Schäfle – on behalf of the editorial team

Rosenheim in June, 2024

PTEE 2024 SPONSORS

The sponsorship is gratefully acknowledged:

DIVERSIFICATION IN PHYSICS TEACHING BY TRANSFORMING PANDEMIC-ERA LEARNING THROUGH OPEN INTERACTIVE TEXTBOOKS

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Electricity and Magnetism is a 1st-year course for about 250 students in the initial stages of the BSc in Applied Physics at TU Delft. For this subject, we created an open, interactive textbook consisting of short videos with descriptive texts and python calculations as illustrations. In this article, we describe how we arrived at this textbook, what its content is and how we now use it in our teaching.

Keywords: blended learning, open textbooks, diversification.

INTRODUCTION

The subject Electricity and Magnetism (E&M) works from basic concepts like charge, fields, and potential to Maxwell's laws. Direct and alternating current circuits are part of the subject content. With this, many different new concepts come along for students. It is important to learn to identify well which part a question relates to (e.g. electricity / magnetism / waves; static / dynamic; direct current / RC switching / alternating current). For students, it is the first introduction to integrating over lines, surfaces, and volumes. In the subject, we as teachers emphasise conceptual understanding and problem solving using physical understanding.

Until the outbreak of the covid pandemic, we taught our subject with 2 hours of lecture and 2 hours of exercise class per class block. The lectures included introduction and explanation of the material, example assignments or illustrations of the application of the learned material in practice or in our research and demonstrations, e.g. the Van der Graaff generator. In the working lectures, immediately following the lectures, students worked on selected problems under the guidance of the lecturers and a team of teaching assistants.

One of the problems we encountered with this course every year was the diversity in students' entry knowledge. Some already have a good understanding of the mathematics being used through a more advanced mathematics at school, others already have a basic knowledge related to E&M through self-study or self-chosen projects. In particular, the practical application of integrals and integration over spatial coordinates (lines, surfaces) presents difficulties for a large group of students. In addition, there is a sizeable group of students struggling with the transition from secondary school to university and all the changes this entails, including the faster pace. In the lectures, the extra explanations that are occasionally needed lead to a slackening of the attention of the better students, while at other times the fast pace leads to the students who are struggling with this at that moment dropping out. In both cases, this leads to buzz and commotion in the lecture hall and a less efficient learning process for the individual student.

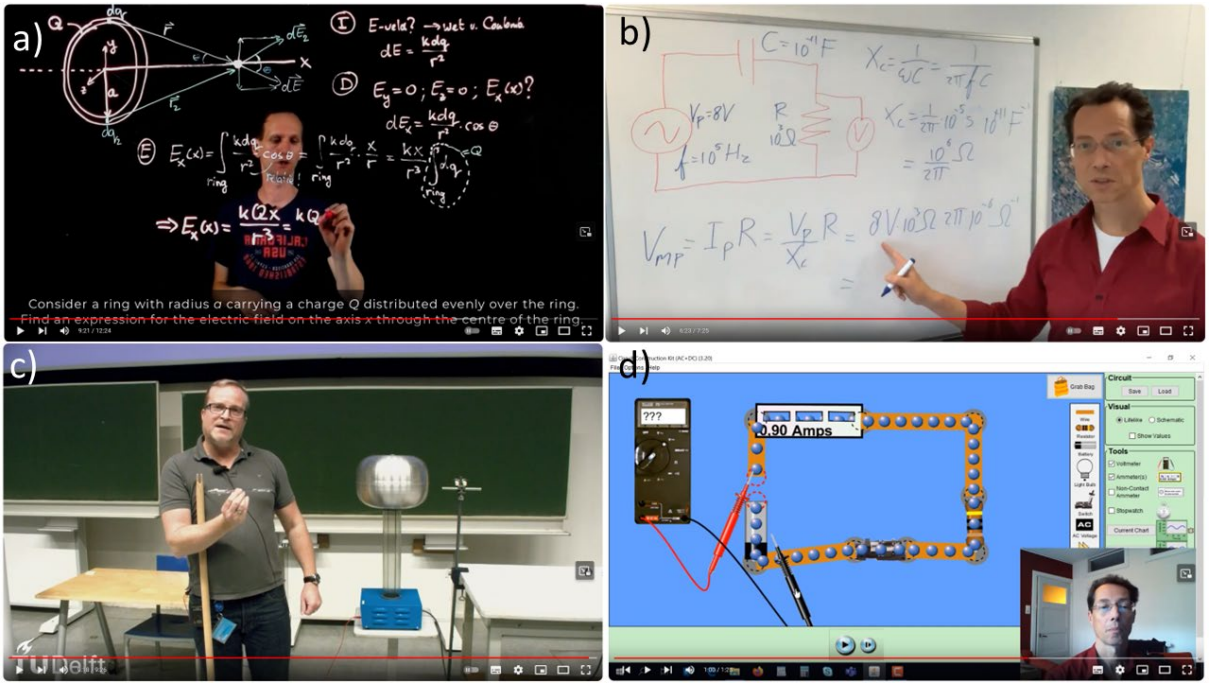

Fig.1. Fig. a) Some videos were recorded by writing on a glass plate and then digitally mirroring the image. This was a challenge with the right-hand rule with the Lorenz force. b) Others were recorded in front of a whiteboard. c) Demonstrations were recorded in the lecture hall. d) Physlets were recorded via screenvideocapture.

VIDEOS

In 2018, we therefore participated in a pilot 'blended learning'. We made short (5-10 minutes), supportive videos on some difficult topics such as integrating on spatial coordinates and videos with step-by-step elaboration of difficult example assignments. This way, students who struggled with this could go through the material at their own pace before or after the lecture.

With the experience of recording several types of videos (see Fig. 1), after the outbreak of the Covid pandemic and the shutdown of physical education, we decided to make a virtue of necessity. In summer 2020, with the support of the blended learning team, we recorded our entire subject content in short videos. We also developed an online learning environment in the digital learning environment where students had a focused task list consisting of modules before each lecture. Within a module, the short instructional videos are interspersed with tasks related to the subject matter. There are also videos with experimental demonstrations by our colleague Ron Haaksman and instructions on how to use online simulations [1].

Student evaluations were unprecedentedly positive following the course in this online version. Many students said they liked being able to go through the material at their own pace and being able to look back at certain explanations when doing an assignment or preparing for the exam. Nevertheless, the live, personal contact with lecturers, assistants and fellow students was obviously missed.

DIVERSIFYING LEARNING

With the return to regular teaching, we wanted to combine the benefits of working with the short videos with our campus college teaching. To this end, we adapted our lecture structure and developed an open interactive textbook (OIT) [2] for our subject. The OIT is a Jupyter

Notebook in which the videos are presented and explained in clearly structured chapters. In addition, there are computational examples in Python as illustrations and simulations.

In the new lecture structure, each 4-hour class block starts with a 1-hour plenary lecture. In this lecture, the outline, and main concepts of the material for that day are explained. There is also room for practical demonstrations. After this lecture, students work for 3 hours on the material for that day, with lecturers and a team of teaching assistants walking around for support and questions. Students work either independently or in a group and study the material covered interspersed with exercises. With the OIT, they can choose to use the regular textbook or just watch the videos.

Using our OIT, students can set their own learning pace for the various parts of the subject. Students who like to attend lectures have this option for the first hour, but students who prefer to work independently can start at home and join working lectures for the second hour. It also offers a solution for the large group of students who in the first months still live at home, sometimes at a considerable distance from Delft. They can choose at what times they travel to Delft to attend the sessions in person and ask targeted questions on the topics they are struggling with. Feedback from students is predominantly positive and confirms the goals we had set with this form of education.

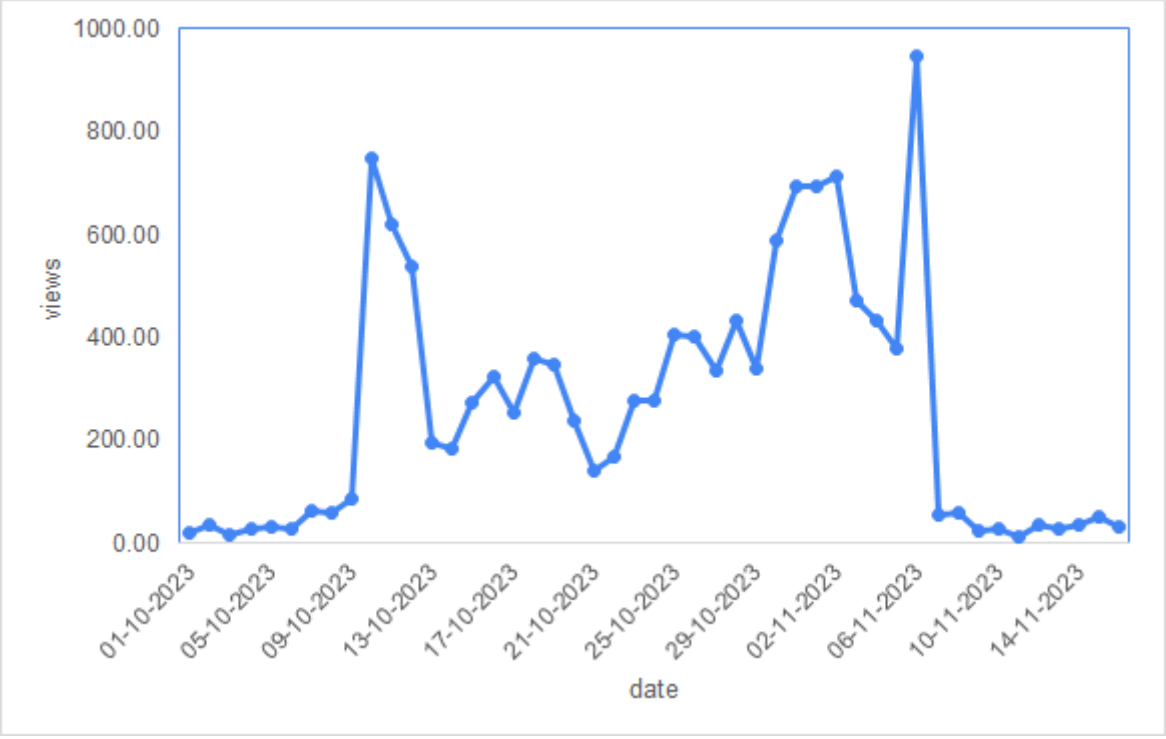

Fig. 2 Number of views of the videos per day during the teaching period in the fall of 2023. The first peak is on the first day of exercise classes. The last peak is the day before the exam.

RESULTS AND FEEDBACK

In the general evaluations, there are many positive comments about the videos. Students like the fact that they can watch at their own pace whenever they want. A small proportion would still like more ordinary lectures. Students experience the videos as lectures. The book is different study material in the eyes of the students. They are satisfied with the OIT compared

to the YouTube channel alone because it gives them an overview and makes it easy to find topics.

In the viewing figures, we see that students mainly watch during the days with the working lectures, but also on the other days throughout the period, with a peak the day before the exam and a small peak before the re-exam.

We see no notable change in exam grades. Some students indicate that they lack the self-discipline to still go to the working lectures when they can watch the lectures from the OIT.

CONCLUSIONS

The incorporation of the OIT into mainstream education helps diversify learning pathways. Thus, it better meets the learning needs of individual students. This leads to a more efficient learning process with focused lectures for a group of interested and active students and, at the same time, more time and attention from lecturers and assistants to the problems experienced by each student themselves.

Because the entire OIT is presented in Dutch, it can also be used at other Dutch institutions including polytechnics, and by professionals or self-employed people who want to brush up their knowledge on electricity and magnetism. We look forward to experiences and feedback from external users to further develop and optimise our OIT.

ACKNOWLEDGMENTS

We thank the Open Interactive Textbooks project team of the TNW Education Team. The development of the OIT was made possible by the financial support of the TUD Library through the Open Education Stimulation Fund.

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[1] https://phet.colorado.edu/

[2] Bouwman, W. G., Hoogenboom, J. P., & Haaksman, R. P. H. (2023). Introductie Elektriciteit en Magnetisme. TU Delft OPEN Publishing. https://doi.org/10.59490/tb.77

WHAT I WISH I HAD KNOWN … WHEN I STARTED (ACTIVATING) TEACHING IN PHYSICS

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The benefits of activating teaching methods are promoted by many colleagues and have been proven by numerous studies. Nevertheless, experienced instructors often do not switch to those methods in their teaching, and first-time lecturers start with traditional instead of activating methods. This article is aimed at (future) educators who are thinking about implementing such methods, as well as experienced ones and educational support staff who wish to provide support for their colleagues. This report is based on personal experience, (free-response) evaluations, standardized tests, and literature. It shows, which factors supported the introduction of and transformation to activating teaching methods, which made it difficult, and which would have been helpful. It is demonstrated why a changeover is worthwhile for physics educators despite possible risks and setbacks.

Keywords: Higher Education Pedagogy, Quality Teaching, Active Learning, Academic Development, Novice Teachers

INTRODUCTION

Effectiveness of and caveats concerning activating teaching methods

Activating teaching methods (i.e. teaching methods that intend to evoke active learning in students) have various positive effects: students gain a better understanding of physical relationships, they are met at their knowledge level and develop an interest in physics, the teaching is perceived as more interesting and effective by both teachers and students, dropout rates are reduced, students perform better in exams and standardized tests, and the contact with students is improved and more intensive (e.g. [1], [2], [3], [4]). Research in physics (and science) education clearly indicates that these methods are superior to traditional lecturing.

Nevertheless, the transition from traditional to activating methods is happening only reluctantly. The hesitation of doing so could partially result from narratives of colleagues that are certainly enthusiastic, but regularly do not disclose difficult situations and critical aspects about the transition and implementation process. Given the time pressure faced by instructors, locating and contextualizing this important information from various papers within a reasonable timeframe is challenging.

Purpose of the article

This paper aims to encourage all, but especially novice instructors to explore alternative teaching methods. Additionally, it offers insights for institutional staff on how to foster a conducive environment for activating teaching methods. With the word “instructors” I subsume all staff with teaching duties, e.g., professors, lecturers, and teaching staff.

Thus, the article delves into helpful aspects such as personal and financial support, as well as feedback in a first section. Subsequently, the topic “what I wish I had known of” is explored, encompassing general aspects, impediments, and concerns that might be beneficial to know before implementing activating methods. These are categorized into the areas of frustration and other feelings, time pressure, the necessity for professional relationship management, and the possibility of unfavorable evaluations. Third, the paper addresses

aspects that would have been helpful for me to ensure a smooth and lasting transition to activating methods, namely institutional support, specific feedback and role models.

Personal stance

I find the disclosure of my personal and pedagogical stances an important part for this paper in agreement with [5] since only thereby the listed experiences and conclusions are credible, interpretable and contextualizable. They guided the design and execution of my teaching, my perception of teaching, and the insights I gained for this paper.

Instructors should, in my opinion, be **friendly and respectful** towards students and show **interest** in them as learners and persons. This is e.g. expressed by fostering an inclusive and supportive atmosphere rather than inducing fear of the teacher, as also mentioned by [6]. This mindset, along with corresponding behaviors, should be adopted for ethical reasons, but research showed, it also increases student performance [7] and enables instructors to recognize and seek ways to overcome possible barriers [8].

In accordance with Hattie [8], I think that instructors should care about "solving problems with respect to **individual students' performance** in the class" rather than generally focusing on the entire class. I observed, that students enter our university and my courses with their own "**backpacks**". These are filled with, for instance, difficult family backgrounds, financial or psychological problems, or difficulties with the course language, as also witnessed by [9]. Therefore, negative emotions like anxiety and hopelessness can easily result and lead to disengagement of single students or whole groups with the course.

Students arrive with their own **motivation** in our university and in my courses. However, I think, this does not absolve me from motivating them for my courses and the content that we cover together during those courses, e.g., through ensuring a feeling of self-efficacy, their sense of belonging, and their perception of the quality and relevance of the curriculum, as also mentioned in [10] and shown in Fig. 1. [11] and [12] stated that raising motivation is also possible through increasing the situational interest of students, e.g. through doable challenges, meaningful choices, novelty of or within the tasks, appeal to students' imagination, or surprise. My impression is, that reasons for demotivation and disengagement, or even for quitting an academic task, often lie in the difficulty of the concepts covered (but usually not the "laziness" of instructors or students).

Some (more) interesting **myths about teaching** are revealed in [13], e.g. the idea of learning types, that would have to be specifically addressed (and we intentionally did not address).

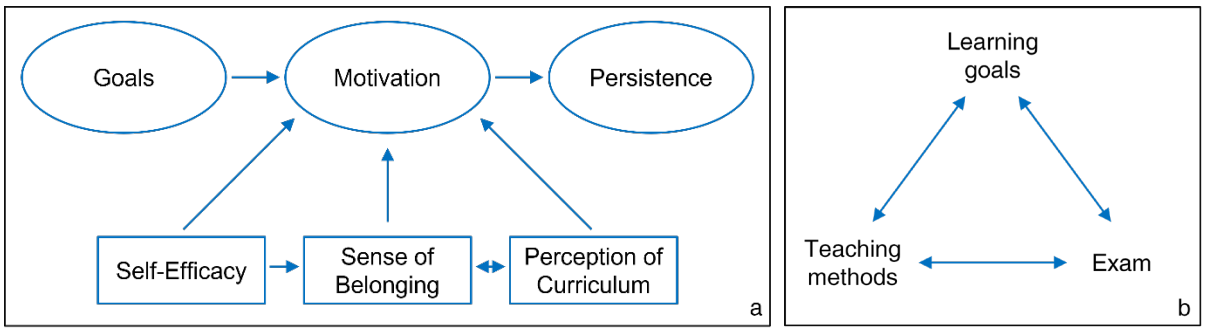

Fig. 1 Two important concepts in the personal and pedagogical stance: a model for student motivation (a, [10]) and constructive alignment (b, based on [14]).

Pedagogical stance

My pedagogical stance is most relevant to this paper because it influenced the selection of teaching methods as well as their practical implementation.

I find the concept of **constructive alignment**, as proposed by Biggs in [14] and [15], essential (Fig. 1). Here, learning goals, teaching methods, and the exam have to be aligned to each other. In my physics courses, learning goals include the acquirement of a deep **conceptual understanding** and the **resolving of common misconceptions** (as discussed by Kautz in [16]) of critical concepts from mechanics, thermodynamics, fluids, electricity, and oscillations and waves. To achieve that, I decided that students must actively engage with the content. Therefore, I chose to implement activating teaching methods in the physics courses.

Nevertheless, from my experience, student-centered teaching is not preferable to content-centered teaching in every situation. To reach the best student learning outcomes, adaptive behavior of the instructor and the choice of a good teaching method depend on the intended learning goals to be reached, as was also stated in [8] and [13]. Additionally, Ulrich shows in [13] that not only deep learning, but a strategic mixture of surface and deep learning enhances the learning success.

METHODS

Institutional background

As a University of Applied Sciences, we cater to a diverse range of students from different social, educational, economic, family, and cultural backgrounds. The university is located in one of the poorest states in Germany.

I have been teaching physics since 2020, commencing right at the beginning of the COVID-19 pandemic, and immediately implemented activating teaching methods [3] along with a restructuring of the physics courses. After a decision-making process, the physics group at our university, comprising two professors and myself as a lecturer, decided for the introduction of Just-in-Time-Teaching (JiTT; [17], [18], [19]), peer-instruction (PI; [20], [21], [22]), and *Tutorials* ([23], [24], [25]) in all the first-year physics courses. However, this shall not give the impression of a general superiority of these teaching methods over other activating methods. The decision was based on the conditions (e.g., size and diversity of the student groups), teaching situations (e.g., availability and (non-)existence of certain rooms), and learning goals.

Data basis

The main source of practical insight is personal experience and here in particular self-reflection and talks to students and colleagues. Additionally, interim and final evaluations were conducted during lecture time in each course, which included the following four questions: “What do I like about the physics module?”, “What do I not like so much?”, “What suggestions for improvement do I have?”, and “Anything else I would like to mention.” Two courses have completed a comprehensive online questionnaire at the end of the first semester.

WHAT I GOT THAT WAS HELPFUL

Personal assistance

Colleagues provided prompt and personal assistance for questions regarding the implementation of the methods, especially when general or specific problems arose. Without the exchange of materials (e.g., PI questions) and experiences in networks (e.g., from the European Society for Engineering Education, German Physical Society, or the Bavarian Center for Innovative Learning), such a comprehensive and rapid introduction of the methods

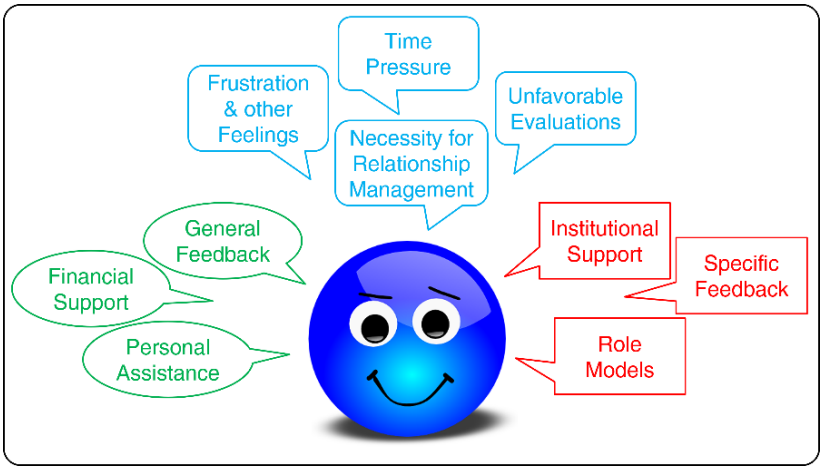

Fig. 2 Helpful aspects (green left ovals) for implementing activating teaching methods, aspects I wish I had known of beforehand (blue top rounded rectangles), and aspects that would have been helpful to have or to obtain (red right rectangles).

would not have been possible. I was not aware of how crucial these networks are for successful implementation of the chosen methods.

The decision to transformation to activating teaching methods was made collectively within the working group. This resulted in strong support for the retention of activating methods and a will to solve occurring problems rather than stepping back from the transformation.

Financial support

The transition to activating teaching methods was facilitated by funding from both a national and state fund[1] and a junior fellowship[2]. These funds allowed the hiring of a colleague and undergraduate assistants who supported various aspects, such as preparing materials, creating online environments, searching for relevant resources, assisting in teaching, and taking over a portion of my instructional responsibilities. Consequently, this support granted me increased flexibility with my time. Furthermore, the allocated funds facilitated the procurement of teaching materials essential for implementing the methods.

I was very lucky to benefit from sufficient funding. In general, there are not enough funding opportunities for projects with the goal of transforming a single course from my university (none), state (none) or nation (only “Stiftung Innovation in der Hochschullehre”). European funding is not available if only one university or even one course is included.

General feedback

The close interaction with students, both online and in-person, was not only individually satisfying and allowed to develop a strong rapport with the students but also provided valuable insights. This facilitated numerous feedback opportunities regarding the students' level of knowledge and my teaching methods, contributing to a comprehensive assessment of the teaching progress.

Within the university, the transition received recognition and appreciation from the faculty through approved projects and an awarded teaching prize. The trust of the project sponsors in a newcomer like me meant a lot to me personally and gave me courage for the implementation.

[1] Hochschulpakt: https://de.wikipedia.org/wiki/Hochschulpakt
[2] Stifterverband für die Deutsche Wissenschaft: https://www.stifterverband.org/english

WHAT I WISH I HAD KNOWN OF

Frustration and other feelings

I was greatly **disillusioned** with the extent of the lack of prior knowledge among our students, which had previously been assumed by my colleagues and predecessors. It was very frustrating for me, because it rendered parts of my class plans obsolete as awareness of the knowledge gaps required action on my part. Therefore, I could cover even less content than originally planned. It was disheartening, because I felt unable to convey my fascination for physics due to the absence of prerequisites.

Students were frustrated by the new, unfamiliar teaching approach. In their perception, the instruction was deemed excessively difficult, leading to exam-related anxiety. They felt humiliated due to their frequent errors (that I and the materials provided provoked as part of the learning) and their perceived lack of comprehension, as well as a substantial time commitment for the course. Additional challenges were faced by international students (proficiency level B2 is sufficient for entering the university), as language plays a central role in activating methods. For some foreign students, the teaching approach was partially experienced as discriminatory.

I often felt **insufficient and incompetent**. The methods frequently did not unfold as planned. For instance, in the methods chosen, the *Tutorial* worksheets were too lengthy and challenging. In lectures, students did not participate in discussions with their peers, some students even watched football, and a significant proportion did not attend the classes at all. Often, I found myself at a loss with the numerous open questions I received within the weekly quizzes (implemented within the JiTT framework). Nevertheless, I enjoyed the process of deeply working on physics-related topics, and I believe that I have gained a different understanding of many concepts of physics myself.

I was **sad and angry** as the relationship with some of my colleagues was strained due to the transformation of my teaching. The reasons for this strain can only be speculated; some colleagues felt "attacked" by my adoption of "newer" teaching methods, while others accused me of being arrogant and condescending because I did not build on their experiences. The significant gap between the state of educational research and the reality of teaching at my university sometimes limits exchanges regarding teaching, e.g., because the importance of formulating learning objectives, deep conceptual understanding, or the usage of activating teaching methods is not universally acknowledged. I underestimated how crucial it would have been to collect data to demonstrate, that activating teaching is effective also within our university as suggested by Foote [26]. By now, I think it is okay to transform teaching "for oneself". I wanted to use activating teaching methods because I believed it was the right approach, I would **enjoy it**, and I wanted my students to understand physics.

The transition to activating methods is never "complete", as I am in constant and intense exchange with the students. The inability to be "finished" is, on the one hand, **disappointing**, but on the other, it keeps teaching **exciting**.

Time pressure

The teaching methods and implementation plan seemed logical, sensible, and feasible, having been discussed with experienced educators. However, the **implementation proved more time-consuming than anticipated** as also observed by [27], with recurrent technical issues. Institutional support, particularly in educational technology, was lacking, and the hired staff member was absolutely necessary to manage the tasks at hand.

I could not find **suitable literature** that aligned with the learning objectives of the course and succinctly presented the key content accurately. Textbooks were either too lengthy, too difficult, or contained errors. This led us to write all reading assignments ourselves.

As a consequence of the switch to active learning methods, a further change to the course structure would now be **very labor-intensive** and possible only with external support, making the content and course sequence inflexible. In a traditional lecture, I could quite easily swap topics. However, this is now time-consuming, as the course in the learning management system would need to be reconfigured (create new folders, delete and upload new contents, group it, generate new questions for quizzes, find or write new reading assignments).

Necessity for Relationship Management

During my first semesters of teaching, I was not aware of how much I needed to be a leader and professionally shape the relationship with students at all levels. This is why I initially did not do this to the extent that would have been necessary. For me, it was very difficult to find the balance between establishing a good, respectful, equitable, warm, and appreciative relationship with low social distance, while also using my "position of power" to **introduce and enforce rules** in the classroom. The latter were, e.g., maintaining quiet and banning the use of smartphones during class, and clearly communicating my expectations that students come prepared and on time to lectures. **Ensuring compliance** definitely had a positive effect on the students' performance and, ultimately, was not as difficult and unpleasant for me as it felt beforehand. The positive effects I experienced are in accordance to Ulrich, who showed that demonstrated leadership behavior (e.g. professional relationship management) has positive effects on students' performance and evaluations [13].

Unvaforable Evaluations

Feedback from students was generally **constructive and positive** (e.g., specific identification of what they liked and found helpful). Disappointingly, there were occasions when negative feedback was publicly expressed, and became known and significant within the university. In this context, it would have been helpful to me to know that student dissatisfaction with active learning has been observed elsewhere:

"While lecture-taught students' evaluations of the experienced teaching were generally focused and positive, students' perceptions of the activating methods varied widely and both extremely positive and negative opinions were present" [28]. This **variability** can partially be attributed to factors unrelated to the actual quality of teaching [29], such as gender of the instructor ("In physics, female instructors are often rated 7–13% lower than males."), stereotypes (evaluations encourage "whatever biases students have, implicit or explicit"), and **expectations about teaching and exam results** ("If students go in thinking they will get a good grade, they give higher evaluations.").

Wieman [27] observed, that evaluations remained unchanged within statistical uncertainties when faculty received specific guidance on how to get student buy-in and when multiple courses[3] within the university were transformed to making use of activating teaching methods. Then, evaluations of the faculty who had not changed their teaching had gone down. This suggested, that the **students' standards were changing** as a result of their exposure to research-based teaching methods and that faculty guidance is crucial.

WHAT WOULD HAVE BEEN HELPFUL

Institutional support

Our university lacks typical **faculty development tools** like peer **discussion groups, mentoring programs, classroom observations**, career counseling, workshops on (engineering) education, and sabbaticals for staff except professors [30]. As noted by other

[3] 71 courses at Columbia University and 164 courses at the University of British Columbia

researchers [30], [31], this lack of concrete help with scholarship and teaching was disappointing and hindered my progress. I would have found the first three tools most helpful. Wieman [27] reported, that almost none of the faculty adopted new teaching methods without the support of science education specialists providing support and guidance in some form.

To conduct JiTT, it is necessary to collect students' open questions and issues before the lecture, which we implemented through our learning management system. However, it is neither feasible to promptly assess all students and provide individual feedback, nor was there **technical support** available at our university.

Specific feedback

Boyden [30] showed, that inadequate feedback, recognition, and reward stresses new faculty and points out, that improvement of teaching practice develops through inquiry and dialogue that is critical, reflective and constructive, taking place in social contexts with supportive peers. Collaborative groups (also known e.g., as peer discussion groups, professional learning communities) could provide such a social context, network, and supportive structure [32].

Role models

I would have needed colleagues on site who could have given **personal and mental support** and, for example, expressed that we were on the right track, the implementation was going well, and that it would be easier with time and more experience. I would have needed specific feedback on my teaching and the implementation of the methods. Without this feedback, it took me at least four semesters until everything ran smoothly overall.

In particular, **female colleagues and their personal experiences** would have been helpful, e.g., how they shape their relationships and their interactions with students, or how they ensure a balance between time-intensive teaching duties with family and personal needs.

CLOSING STATEMENT

Would I embark again on the endeavor of (radically) transforming my teaching? **Absolutely!** It was a very demanding time with many hurdles to overcome, and the efforts will continue, albeit in a milder form. However, there were also many aspects that were absolutely worth it and that I would not want to miss anymore.

For example, the intellectually intensive discussions and personal conversations that arose with students, the closeness to the needs and problems of the students, the gratitude from many students, and the positive feedback from them, the good results in the Force Concept Inventory[4] [33], [34] and other assessments, as well as the increase in the courses' passing rate from 49% in 2021/22 to 55 % in 2022/23 to 65% in 2023/24 (in the first exam offered). It took three challenging years until these positive effects outweighed the negative ones.

Let me close this article with a small selection of quotes from students on the course:
"Physics is cool!!!"
"I have made it a motto, among other things, because of you: What I can't do today, I might be able to do tomorrow."
"You're doing a great job, and I've really become fond of and enjoyed the module."
"You always give me the feeling/motivation not to fall behind and to stay on the ball. I find this to be a great enrichment and it always motivates me to make up for certain deficits through hard work and ambition. Probably not everyone perceives it that way, but you have helped me tremendously with this. So again: Thank you very much, and keep up the good work! ;)"

[4] pre-test: (10.6 ± 0.2), post-test: (17.1 ± 0.2), average gain: 0.34, average normalized change: 0.35

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MOMENTECH - MODERN EXPLORATIONS OF THE IMPULSE-MOMENTUM THEOREM

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Herein we outline the design and construction of an instructional laboratory demonstration of the conservation of linear momentum, by way of the Impulse-Momentum Theorem, utilizing small, commercially available accelerometers attached to microcontrollers. The set-up is equipped with small, OLED screens which are able to display real-time acceleration graphs. Furthermore, a template for an experiment involving this set-up is provided. We also explore various data analysis options for different levels of student sophistication.

Keywords: Impulse-Momentum, Conservation, Microcontroller

INTRODUCTION

Conservation of momentum is a fact of life in the observable universe. However, one could be forgiven for doubting its immutability given the data that students often come up with when trying to demonstrate it. The traditional instructional lab experiment designed to demonstrate conservation of momentum is usually, and reasonably, based around the collision of two masses. Often such collisions take the form of wheeled carts of adjustable masses rolling along grooves on a graduated track. The data measured can vary but will usually be some combination of displacement and time. Depending on the measuring equipment available, we have seen experiments wherein carts with flags of constant width pass through photogate-timers before and after the collisions, allowing for direct computations of initial and final velocities [1]. Furthermore, in less equipped, but no less resourceful labs we have also seen very clever designs in which students are able to indirectly test conservation of momentum by confirming the following equality [2]:

$$\frac{m_1}{m_2} = \frac{x_2}{x_1} \tag{1}$$

where m_1 and m_2 are the masses of the carts and x_1 and x_2 are displacement magnitudes of the carts after the collision. This implementation has the benefit of not requiring the measurement of time, thus appealing to laboratories with limited equipment.

Nevertheless, these, and other implantations involve the performance of an often-complex set of measurements, followed by a series of calculations which can seem far removed from the observed dynamics. In the case of the demonstration involving photogates, students need to arrange for a collision to take place between a pair of photogates, while simultaneously being aware of which carts passed through which photogates, and in which direction, before and after the collisions. While not a difficult task for a physicist, for a student still learning physics, the attention to detail needed to perform the experiment and correctly collect the data can often take up attention that might otherwise be used to observe and reflect on the dynamics while they are

occurring. Furthermore, once the experiment is over and data analysis begins, it becomes an exercise in book-keeping, as a set of initial and final velocities and then initial and final momenta are computed and then compared. Even in the case of an experiment with excellent data, the fact that two data columns have similar numbers can seem distantly connected to the actual experiment in the mind of a student just learning about conservation of momentum.

Indeed, that pedagogical disconnect is there even under the best of circumstances, when the experiment is done well and the data work out. Oftentimes, however, there are non-negligible problems with the implementation of a given conservation of momentum experiment, resulting in systematic errors overwhelming the student's calculations. In the worst of circumstances, one can have students orchestrating a distractingly complex experiment, only to get numbers which then don't even come close to working out. None of this is the fault of the student and yet it still can be extremely frustrating to even the best of students, and disheartening to the underperforming, though sincere students trying their best to engage with and learn from the lab.

IMPLEMENTATION

It is with the hope of improving the situation described in the introduction that we have developed an entirely new (as far as we know) approach to demonstrating conservation of momentum.

The first improvement has been to automate the data collection, though it is not a step taken lightly. Introductory classical mechanics experiments very often prioritize the measurement of the fundamental, observable quantities of time, mass, and length, with calculations of constructed quantities to be done as part of the analysis. While we very strongly support this pedagogy and methodology, the issues with the implementation of conservation of momentum labs reveal a need for methodological flexibility in order to improve pedagogy. By the time an average physics lab class gets to momentum, the students have already measured lengths and times and computed accelerations themselves, many times over. We, therefore, believe that it is not unreasonable to trust the students to accept that one can automate the measurement of acceleration with an electronic accelerometer, the functioning of which is to be explained to the students. Indeed, that explanation is an excellent opportunity for students to see how the very physical principles and measurements they have been doing in class thus far can be manifested electronically and on a microscopic scale.

With the data collection automated, students merely have to focus on pushing carts towards one another, freeing up their mental bandwidth for noticing the phenomenological behavior of the carts before and after collisions, e.g. exploring questions such as "How do carts with different masses move after the collision?" or "What happens if one pushes a light cart extremely quickly into a slower, but more massive cart?"

The second improvement is one of visualization. We use microcontrollers which either have OLED screens built into them, or to which we have wired such screens, to display live acceleration versus time graphs. The screens are too small for detailed analysis (that comes later); however, they can graphically show the real-time behavior and direction of the acceleration of the carts. We believe that this display can help with one of the greatest, in our experience, conceptual disconnects experienced by physics students: the idea of observed motion in one direction, but acceleration in another, or opposite direction. With signed, real time acceleration data displayed, students can play with the carts by moving them to and fro and seeing how the acceleration graphs on each cart spike or dip in concert with their movements. Indeed, they can start to conceptualize the experiment's collision itself as a sudden

spike in acceleration, with a corresponding spike in net force, and thus in impulse. Ultimately, we believe that this can open the door to showing students that physical interactions are ultimately manifestations of energy and momentum exchange, via work and impulse, respectively.

Our third improvement is in data analysis. We describe here the overall methodology of our data analysis, but specifics can be found later in the eponymous section. In the experiment as performed at City Tech [1], and in other physics departments, the ultimate goal of the data is to demonstrate numerically that the total momentum before the collision is equal to the total momentum after the collisions, within an acceptable margin of error. As mentioned earlier, showing that some number almost equals another number is not as illuminating as it could be. If the numbers aren't almost equal, then the student is often at a loss to figure out why, or even what those numbers physically represent, especially if the experiment itself was also convoluted to implement.

We believe that impulse is the way out of the data analysis problem, but rather than computing it as change in momentum, we appeal to the Impulse-Momentum Theorem and numerically compute the following integral:

$$\vec{J} = \int_{t_i}^{t_f} \vec{F}(t)dt = m\int_{t_i}^{t_f} \vec{a}(t)dt \qquad (2)$$

The acceleration $\vec{a}(t)$ is approximated numerically with the data logged by the microcontroller and the accelerometer. The resolution of the approximation can be fine tuned by simply adjusting the sample rate of the microcontroller via programming. The integral itself is then numerically computed using an accompanying spreadsheet script. Once again, the accuracy of the integration can be fine-tuned by using various integral approximation routines, e.g. mid-point rule, trapezoid rule, etc. Indeed, this allows for a vast degree of pedagogical customization. A non-calculus physics class needn't get into the details of how the script finds the area under the force vs. time curve, only that that area is the impulse and the total area of both carts must sum to zero. Meanwhile, a physics-with-calculus class can be asked to investigate if different area approximation routines yield better or worse experimental results. A still more advanced class can be encouraged to implement area-approximation routines of their own design.

Regardless of the mathematical and programmatic sophistication of the students, the idea is to prove conservation of momentum by showing that the total impulse of the system is zero, i.e. that the areas under the force vs. time curves for the carts add to zero, within an acceptable margin. The data analysis now goes from trying to match up two numbers (initial total momentum and initial final momentum) to demonstrating that two areas are approximately equal in magnitude and opposite in sign, which is at least visually more engaging and determinable. Furthermore, students can begin to see momentum as a sort of currency for changing motion (along with energy) and collisions as a way for objects to exchange momentum and change each other's motion, but only so long as the total impulse of the interaction is zero. That zero-sum requirement demonstrates that not just anything can happen after a collision. There is a solution space circumscribed by mass and energy.

Furthermore, a wonderful secondary form of data analysis presents itself, one which arguably illustrates a student's conceptual comprehension better than running the numbers. The aforementioned spreadsheet routine will produce graphs of acceleration vs. time from the moment the microcontrollers are turned on to when they are turned off. In addition to finding the spikes and dips which correspond to the collision itself, students can be challenged to

identify other key moments from the behavior of the graph, such as when the carts were pushed, when they were coasting, and when they were grabbed after the collision.

Finally, we note that since the accelerometer is measuring the net acceleration of the system, the force that arises from multiplying it by the cart's mass is the true, experimental net force, including any sources of friction. This is an advantage over other methodologies that determine the velocities of the carts or their final displacements, as those measurements are subject to friction, but do not take them into account.

PROGRAMMING

The initial work on this experiment grew out of our previous work with Arduino microcontrollers. As a result, the primary programming language employed is the C++ variant used within the Arduino IDE. However, a few secondary languages have also been used for data analysis and visualization. Specifically, we have used the JavaScript language of Google Sheets, as well as the TypeScript language for Microsoft Excel. The advantages of using Google Sheets for data analysis are its ubiquitous availability (requiring only a Gmail account to access), the fact that it is free to use, and that it is run entirely non-locally. The final advantage means that students can work on their data at a laboratory computer initially and then access their work later, on any other computer, tablet, or even on their phones.

The Arduino programming for the microcontroller is, itself, not novel. It relies on fairly standard functions and operability of the microcontroller, (integrated) accelerometer, and (integrated) OLED screen. Its key feature, as written, is its easy-to-set sampling rate, allowing for measurements of the acceleration to an effectively arbitrary temporal resolution. We say "effectively arbitrary" because while there is obviously a hardware limit to how often the microcontroller can make calls on the accelerometer, the amount of data it can take in one second is sufficiently large as to make the maximum sampling rate functionally unusable by the student. Indeed, just to have a manageable amount of data for a commercially available lab computer and spreadsheet program, not to mention for a human student with finite time, means collecting data at a frequency significantly below the microcontroller's upper limit. Nevertheless, a sampling rate of 100 Hz, 50 Hz, or even just 10 Hz yields more than enough data to accurately approximate the impulse experienced during the collisions, via numerical integration.

Finally, we are developing a Python based interface with the goal of eliminating the steps involved with using a spreadsheet to analyze the data. As it stands, once the collision has occurred, students upload the acceleration vs. time data either wirelessly or via a microSD chip (depending on laboratory network availability and friendliness). Once the raw data is uploaded, students must then produce plots of the net force and time data. These plots will usually contain extraneous, though not unenlightening, acceleration peaks and dips (see previous section) which must be excluded from the plot in order to focus on the peak and dip which correspond to the collision. Many of the previous steps can be automated using spreadsheet scripts, nevertheless, we are still concerned that too much focus on the minutiae of spreadsheet operations will take away from appreciating what the data are trying to say.

To obviate the preceding concern, we are working on a Python application which can automatically plot the data from the microcontroller and output an interactive graph of the net force versus time (once masses have been set). Students will be able to use a cursor to drag the left and right boundaries of the graphing window to any desired point. The application will then output the area under the curve bounded by the window.

Nevertheless, in both the spreadsheet and Python cases, the programming for the integration routine will be fully accessible and customizable, with options to choose from standard integration routines or to input one's own.

PROTOTYPE DATA ANALYSIS

Herein we present graphical data taken during a test-run of the experiment last summer. The data depicted is indicative of how we imagine students seeing and interacting with the data.

In the test-run, a wheeled-cart ("GREEN") sat motionless on a track whilst a second cart ("WHITE") was pushed towards it. The carts were of nearly equivalent mass (~0.5 kg) and identical microcontroller equipment was placed atop them. The microcontrollers collected acceleration data at a frequency of 10 Hz. Since the masses were considered to be equal, we only graphed the acceleration versus time data for the two carts.

Figures 1 and 2 are the data collected from the initially motionless green cart. Figure 1 is the entire acceleration data which the microcontroller recorded from the moment it was turned on to the moment it was turned off. We can see several points of kinematic interest. The point labeled "G1" represents the accelerations felt when we moved the cart into position and then stopped it. "G2" is the zero acceleration and zero velocity experienced while it sat motionless, awaiting the collision. The collision occurs quite clearly at "G3." The axes of both accelerometers were aligned such that negative indicates leftward acceleration and positive, rightward. Indeed, knowing that alignment, and that the initial velocity of the green cart is zero, a student should be able to deduce from "G3" alone that the green cart was struck on its right side by something moving left. After the collision, we see that it coasted with a constant velocity, indicated by the zero acceleration of "G4" and was then removed from the track at "G5." Figure 2 shows the duration of the collision itself.

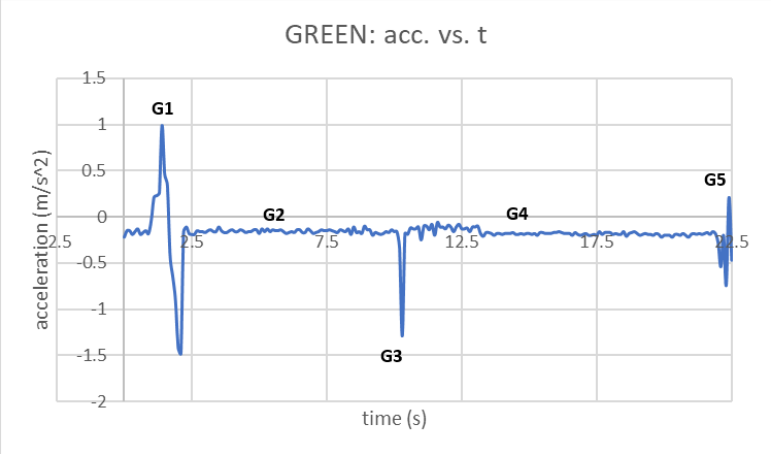

Fig. 1. G1 – Acceleration due to setup, G2 – Cart sits motionless, G3 – Sudden leftward acceleration due to collision, G4 – Moving at constant velocity after collision, G5 – Acceleration due to removal from track

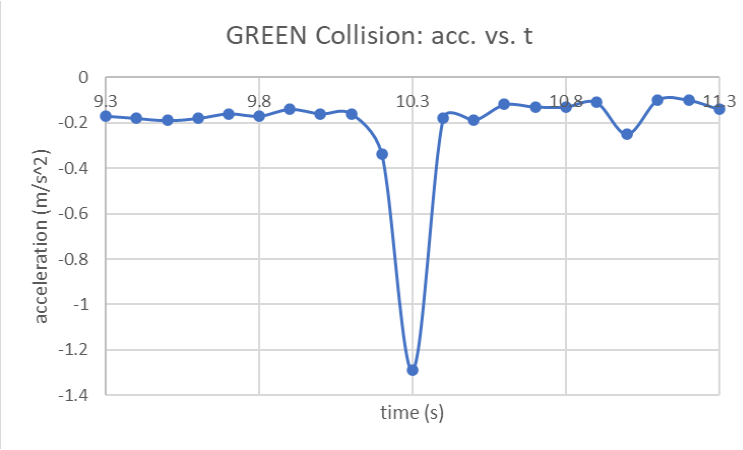

Fig. 2. Moment of collision from stationary cart's perspective

Figures 3 and 4 are of the data collected from the white cart, which was pushed towards the stationary green cart. Figure 3 is the entire acceleration data which the microcontroller recorded from the moment it was turned on to the moment it was turned off. For the white cart, we can see several more points of kinematic interest, given its more dynamic role in the experiment. At point "W1" we once again see several spikes as the cart is manipulated into position. "W2" shows the cart at rest briefly before being pushed and "W3" shows the spike in acceleration as it is pushed to the left. Indeed, an astute student should be able to recognize that that push is, in effect, a leftward collision, just like the one the green cart experiences. At "W4" we see the collision itself. Once again, knowing that the initial velocity of the white cart is negative, a student should be able to look at the graph and identify that a collision has occurred to the left of the white cart and is accelerating it to the right, despite its leftward motion. "W5" represents the post-collision, constant motion of the white cart and "W6" is due to removal of the cart from the track.

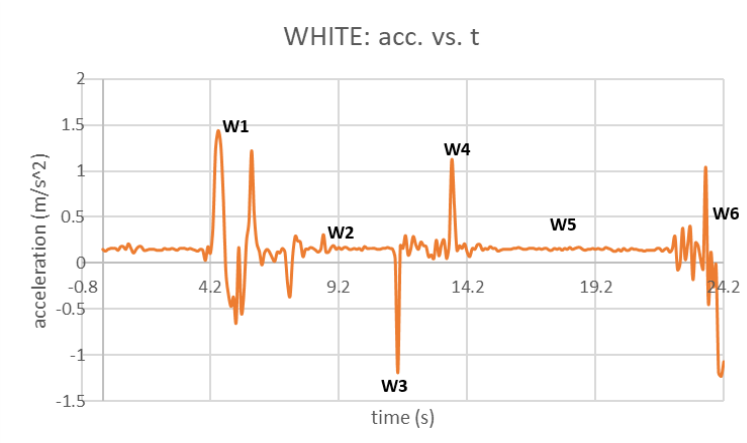

Fig. 3. W1 – Acceleration due to setup, W2 – cart sits motionless, W3 – Sudden leftward acceleration due to being pushed left towards other cart, W4 – Sudden rightward acceleration due to collision with stationary cart, W5 – Moving at constant velocity after collision, W6 – Acceleration due to removal from track

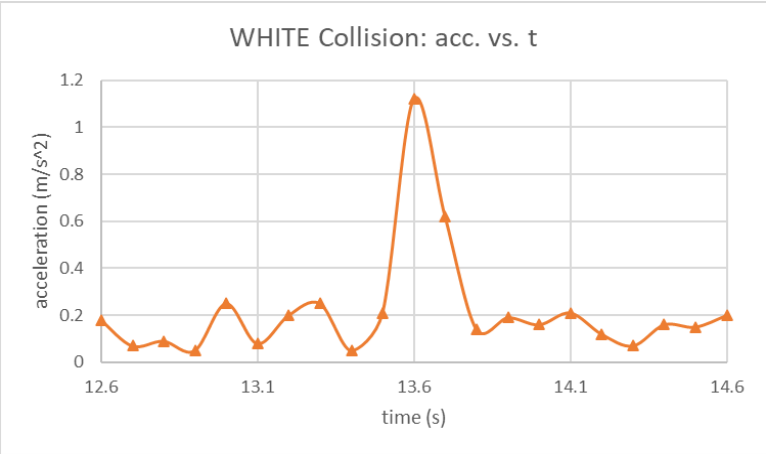

Fig. 4. Moment of collision from leftward moving cart's perspective

Figure 5 simultaneously displays the acceleration vs. time data for both carts during the collision. For this early test-run, a simple mid-point rule integration routine was used. Even so, it yielded a percent difference between the magnitudes of the two areas under the curves of 2.98%. The measurement tolerance for the accelerometers is ± 3% [3]. Finally, the slight, but uniform deviation from 0 m/s^2 on both graphs is a fault of the initial set-up. The accelerometers were not sitting level in the carts.

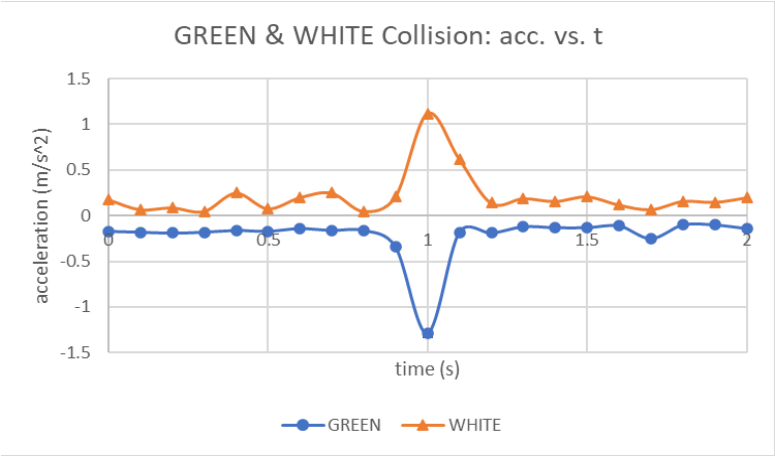

Fig. 5. Side-by-side visualization of areas which should have equal magnitudes

These seemingly simple graphs are shouting at the tops of their lungs about the motion of the carts. It is our hope that this experiment will help students learn to listen.

STUDENT FEEDBACK

In the previous semester, we were able to involve a group of undergraduates in the experiment's prototyping process. During a laboratory class, they ran the experiment using the techniques we have outlined above. In lieu of writing the usual lab report that goes with the experiments, the test students were asked to provide feedback regarding the design and implementation of the experiment itself. In particular, we would like to highlight one student

who realized that the accelerometers were not fully affixed to the carts. She realized that their slightly independent motion would affect the quality of the results. Her attention to detail is so noted.

The greatest insight from the students came in the form of what the experiment's instructions should include. Specifically, we designed a preliminary exercise in which the students are presented with sample acceleration versus time graphs and asked to determine what sort of motion and collisions could correspond to those graphs. To investigate the possibilities, the students would be encouraged to play with the carts, using the live acceleration plots on the OLED screens to get an intuition for what kind of acceleration behavior goes with what kind of motion.

CONCLUSIONS

Collisions happen every day in the observable universe. From colliding galaxies to colliding nuclei in the cores of stars, collisions are how the universe interacts with itself. Nevertheless, while collisions might be easy to arrange, controlling the parameters and measuring the results of collisions is far from a trivial exercise (see every particle accelerator ever built).

We believe that our setup strikes the right balance between automation and manipulation. Our associated method of data analysis and presentation cuts right to the heart of conservation of momentum. The equipment and methodology allow for the students to focus on the fundamental, observable kinematics of collisions, while still quantifying the motion rigorously with data. Indeed, our belief is supported by our own data and by feedback from students. We look forward to further refinement of the experiment and eventual implementation of this experiment in City Tech's standard physics lab schedule.

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LEARNING THE PROCESS OF GAINING SCIENTIFIC KNOWLEDGE

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We present how a teaching unit can be designed to teach the scientific method.

To understand how scientific progress happens, it is necessary to understand the fundamental process by which science generates new knowledge. Teaching the process from observation, hypothesis, prediction, experiment/thought experiment, testing and possibly revising the hypothesis to a theory poses several challenges for the teacher. We will show how we let our students carry out this process themselves in a teaching unit of 1.5 hours.

Keywords: teaching methods, scientific method, hands-on learning.

INTRODUCTION

In the ever-evolving fields of engineering and technology, where new challenges emerge at a rapid pace, the ability to not just apply existing knowledge but to innovate and discover new principles is more crucial than ever. Yet there often remains a fundamental gap in engineering education: the practical understanding of the scientific method. Despite its critical role in scientific discovery and technological innovation, many engineering students find themselves detached from the process of generating new knowledge through this systematic approach. This disconnect not only hampers their ability to think critically and solve complex problems but also limits their potential for creativity and innovation.

As outlined in the review article by Zalewski et al. [1], which is well worth reading, it was already recognized at the beginning of the 20th century that the confident use of the scientific method is an important goal of physics teaching in engineering education. This method is often taught implicitly by applying it to the teaching of content. This method is used especially in constructivism (see e.g. Möller 1999 [2]). It is used to help students generate new knowledge (see e.g. Guisasola et al. 2002 [3]). However, the focus is always on the physical content and not on the scientific method itself. Here we want to turn the tables and teach the method explicitly by letting the students discover something. This change of focus frees the lecturer from the constraint of having to teach a specific content. Here she can choose the content in such a way that she can illustrate the scientific method particularly well.

Addressing this educational challenge, our paper introduces a teaching unit specifically designed to immerse engineering students in the process of scientific inquiry and discovery. Through a carefully structured 1.5-hour session, we guide students beyond the theoretical aspects of the scientific method, engaging them in a hands-on experience that illuminates the path from observation to theory, following the active-learning concept (recourses can be found in Meltzer and Thornton 2011 [4]). This immersive approach not only aims to bridge the gap between theory and practice but also seeks to instill a deeper appreciation for the intricacies of scientific progress and the excitement of firsthand discovery.

By focusing on the rotation of a rigid body — a concept familiar yet ripe for deeper exploration — we challenge students to uncover principles not previously known to them, thereby simulating the true essence of scientific discovery. This paper outlines the design of the teaching unit, the observations and reflections from its implementation, and the tangible impact on students' understanding and appreciation of the scientific method. In doing so, we aim to contribute to the broader conversation on enhancing engineering education and preparing the next generation of engineers for the challenges of tomorrow.

BRIEF DESCRIPTION OF THE SCIENTIFIC METHOD

The scientific method is an iterative, systematic process that forms the backbone of scientific research and discovery. At its core, the scientific method is a series of steps followed by scientists to investigate observations, answer questions, and solve problems to create new knowledge. This process begins with observation, i.e. recording and describing phenomena in the natural world. After observation, a specific question is formulated that leads to the development of a hypothesis - a tentative explanation that can be tested through experimentation.

Experimentation is the cornerstone of the scientific method and involves planning and conducting experiments to test the hypothesis under controlled conditions. This step is crucial as it allows the isolation of variables to determine cause-and-effect relationships. After analyzing the experimental data, the scientists assess whether the results support or refute the hypothesis. This result may lead to the revision of the hypothesis or the development of a new hypothesis, which requires further experimentation.

The scientific method is not a linear path, but rather a cyclical process of refinement and exploration. Its consistent application ensures the reliability and validity of scientific knowledge. Teaching students to apply the scientific method provides them with a powerful tool for critical thinking and problem solving that is essential in the pursuit of technological innovation.

THE TEACHING UNIT

As the scientific method is very helpful for engineers, we believe that it should be covered explicitly in an engineering course. We do not consider a purely theoretical discussion based on a text to be expedient, as this usually does not leave a lasting impression on the students. A practical implementation of a complete research project is too extensive for a physics lecture and would also distract from the actual method, as there are also challenges in terms of content. We have therefore developed the following teaching unit.

First, teams of 4 to 6 students are formed, as the entire teaching unit is designed as group work.

In preparation for the actual task, the groups are asked to get an overview of the chapter "Wissenschaftliche Arbeitsweisen" in our book "Physik Methoden" [5]. It is not necessary for each student to read the entire chapter themselves, but the groups are asked to divide the task between the group members in this way. They just need to make sure that they know the whole chapter as a team. You can also do this as a "flipped classroom" and give the students this preparation in advance as homework.

It is not easy to find a task in which engineering students can discover "new" scientific findings themselves in a short space of time. What is to be discovered must be accessible and must not yet be known to the students. It is also helpful if the discovery can be found without

mathematical description and analysis, as many students have problems with this. The following assignment has worked well for us:

> "Create new knowledge, new to you, about the rotation of a rigid body while this body is not touching anything else."

Findings that the students can discover are, for example:

a) A body rotates around its center of gravity.

b) There are stable and unstable axes of rotation.

   Or more precisely, that rotations around the main axes of inertia with the largest and smallest moment of inertia are stable, while rotations around the axis with the medium moment of inertia are unstable.

Each group is given several cardboard boxes of different sizes and aspect ratios.

Equipped with the basic knowledge about the scientific method from the preparation, the groups then have half an hour to "explore" the topic.

At the end of this lesson, a 30-minute "conference" is held in which each group shares their findings with their peers in a short presentation. This not only fosters a collaborative learning environment, but also simulates the scientific process of communication and peer review.

OBSERVATIONS AND REFLECTIONS

Several notable observations and reflections emerged during the implementation of the science method experience lesson, demonstrating both the successes and challenges of the approach.

Student engagement and discoveries

First and foremost, it was evident that the students were genuinely engaged and enjoyed the hands-on aspect of the lesson. As we usually run this unit at the beginning of a term, it also reinforces team building within the class group.

It is also worth noting that in almost every class, at least one group discovered the existence of stable and unstable axes of rotation. This finding is significant in that it shows that students were able to discover fundamental physical principles for themselves through experimentation and observation.

A typical sequence for this lesson is as follows:

After reading about the principles of the scientific method, the students briefly discuss the topics that the individual members of a group have learned.

As soon as they receive the "research assignment", they first discuss what rotation means and how a body can rotate if it is not touching anything else. It usually doesn't take long before someone in the class starts throwing up a cardboard box with spin.

This usually leads to a discussion about whether air and air resistance need to be considered. If a group has not concluded that air resistance can perhaps be ignored for the time being, as it probably plays a minor role, the lecturer can intervene and ask how it might be possible to find out whether air resistance is relevant or not. For example, you could look at a body with spin under water in a thought experiment. Another frequently asked question is the influence of gravity on rotation. Here, for example, the question "What movement would you expect on the ISS?" can be used to steer the discussion.

The discussions among the students showed that they applied the knowledge they had acquired in the preparation phase. You can hear phrases like:

"My hypothesis is that ..."

"If the hypothesis is correct, the following should happen in the thought experiment ..."

"You can't prove a hypothesis! You can only support or disprove it with an experiment."

This active application of theoretical knowledge to practical implementation underlines the value of integrating reading and practical exploration in the teaching of methodological skills.

Challenges and lessons learned

During the testing of the teaching unit, several notable observations and reflections emerged that highlight the challenges of the approach.

Without the introductory literature about the scientific method, the whole class sat at their cell phones or tablets and tried to solve the assignment solely through internet research. Not a single person took one of the cardboard boxes and threw it up. They didn't seem to attach much importance to their own observations.

When formulating the task, we initially tried to use the term "free rotation". Most of the students obviously couldn't relate to it. We had much better experiences with the paraphrase "the rotation of a rigid body while this body is not touching anything else".

LIMITATIONS

Critical reflection on the lesson reveals inherent limitations, particularly in terms of the scope and depth of the scientific method that can be explored within a limited timeframe. The one-hour duration allotted for the practical implementation phase limits the ability to engage with the entire scientific method, especially considering the complexity and iterative nature of a scientific investigation.

Ideally, the scientific method involves multiple iterations of hypothesis testing, extensive discussion within a broader scientific community, and mathematical formulation of hypotheses - processes that are time-consuming and require a depth of engagement that a single lesson cannot provide. The brevity of the lesson means that students only gain a small insight into the process of knowledge development and validation within the scientific community.

To overcome these limitations, students can be encouraged to apply this approach and mindset to laboratory exercises or project work later in their studies.

Another way to further engage with the scientific method is to follow discussions of scientific topics in the public or press. This can be done in particular when scientific discourse is abandoned and FLICC methods (fake experts, logical fallacies, impossible expectations, cherry picking and conspiracy theories) are used (see e.g. [6]).

CONCLUSIONS AND OUTLOOK

In summary, our research on teaching the scientific method in engineering education has provided a pathway to a practical and engaging learning experience. By moving from a purely theoretical discussion to a hands-on, exploratory approach, we have not only bridged the gap between theory and application, but also fostered a deeper appreciation for the scientific process among engineering students. The innovative lesson described here challenges students to discover principles through first-hand experience, simulating the true nature of scientific

discovery. Through group work, active experimentation, and reflection, students have shown great engagement and success in discovering fundamental principles such as the stable and unstable axes of rotation.

Although the time and content constraints of a single lesson exist, the foundational experience provides a springboard for applying the scientific method in more complex, real-world scenarios. Encouraging students to engage in scientific discourse in public forums and apply methodological skills in laboratory exercises or project work can further deepen their understanding and skills.

We will continue to refine and expand the educational approach of "teaching methods rather than imparting knowledge" [7]. A study is still pending that will attempt to measure how successful this concept is. Our goal remains clear: to equip the next generation of engineers with the necessary tools for innovation, critical thinking and the pursuit of scientific knowledge.

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LEARNING PHYSICS METHODS IS IT POSSIBLE TO TEACH METHODS INSTEAD OF PHYSICS CONTENT?

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For many years, a team of physicists at the HTWG Konstanz has been shifting the focus of physics education from teaching "content" to teaching "methods". An overview is given on the derived state. Several questions are addressed, such as: What are the advantages? Are there constraints and limits? How can a shift be achieved? What are student reactions and how does other teaching staff deal with the new situation.

Keywords: Physics Methods, Physical Thinking.

INTRODUCTION

Physics didactics mainly deals with two topic questions: "How do we teach?" and "What do we teach?" The first topic "How" can be divided into two fields, one on gears and tools and one on settings (e.g. flipped classroom). "What" can be taught can be further distinguished between teaching physics content on one side and physics methods and skills. The PTEE2024 conference has its focus on "How do we teach" followed by about 30 % dealing with content and a smaller part connected to pre-skills and pre-conceptions (fig:1).

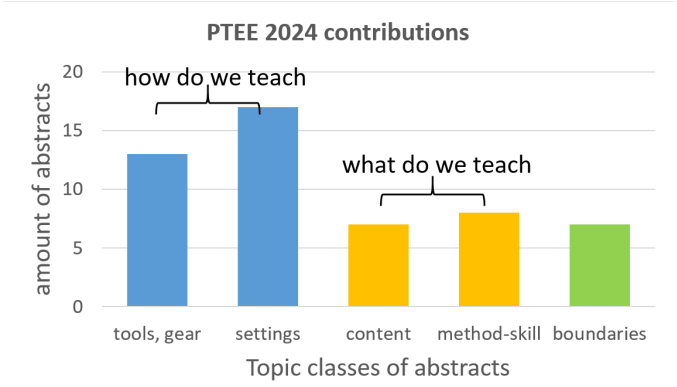

Fig.1: Abstracts of the PTEE2024 conference. Most of the contributions address topics on "How" we teach (blue), about 30 % deal with "What" to teach (orange).

We will give basic ideas and findings on our long journey concerning the "What" and our transformation from teaching "physics content" to teaching "physics methods". The basic question whether "teaching physical thinking is possible" was already asked by Stankowski at the PTEE2011 conference [1].

The principle of exemplary learning was described very well by Stary, et.al [2]. The fact that the general is contained in the particular (mundus in gutta) and that it has therefore long

been suggested that the fundamental should be learned from special examples is even documented there with an old example from physics didactics:

> *"In physics, we used to say: the important things from mechanics and thermodynamics and optics and so on. Instead of these many plus signs, wouldn't it be better to say: mechanics or electricity or ... is something exemplary in physics to be achieved? These would then not be lists of materials, but 'function charts'. They would be certain subject-typical intellectual functions, ways of encountering, which could be experienced 'once and for all' with selected materials." (translated from German; Wagenschein 1959)* [3]

In their extensive overview article on the subject of physics teaching in engineering education PTEE, Zalewski et.al. [4] analyzed the main topics since the beginning of the 20th century. They were able to show that "physics skills" were repeatedly addressed as a major teaching goal. In their conclusions they state: "*... a task for physics and engineering teachers is not just transferring already-built knowledge but helping develop practical skills to apply that knowledge.*" According to their work many institutions have taken steps in the direction of setting such priorities.

For many years our team has been working on ideas for improving physics skills, like “learning the process of scientific knowledge” [5], or extending Labs content [6] and [7]. The leading question during all this work was exactly the same stated in Zalewski’s summary: “Why do we learn physics in engineering?” This led finally to a shift in physics teaching for all physics courses at our university, which will be reported on hereafter.

GOALS OF PHYSICS TEACHING IN ENGINEERING EDUCATION

Since physics is not the main topic in engineering education, the goal of physics courses in engineering programs may be summarized as:

- Goal: Students have physics skills that help in their engineering work.

A skill in this context is a person’s capability to use various methods for finding a solution to a problem or task. For example someone can have the skill to apply a theory to real-world problem. This person can observe reality, use theory to transfer the problem into the language of mathematics, solve the math part and then draw conclusion in order to solve the posed real-world problem.

Such skills can however not be taught directly. Acquiring skills is a process. Skills come with experience. And gaining experience is driven by content. Content is given to students, often as physics topics and questions. They learn tools and methods to solve the posed problems. Various content will lead to numerous methods, and finally (hopefully) will enhance the student skills.

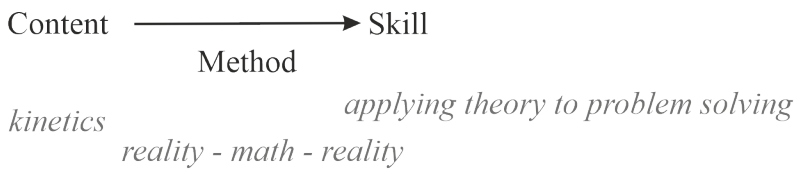

Fig. 2: Model of acquiring skills: When dealing with content (e.g. kinetics), methods are learned (here the use of mathematics) which will essentially lead to improved skills, like applying suited theories to solve engineering problems.

What are possible physics skills that can help engineers in their daily work? The following list combines a good part of essential skills:

- Mastering a full experimental cycle
- Moving from observation to theory
- Applying theory to problem solving
- Approaching tasks
- Dealing with complex systems
- Reasoning
- Entering into unknown fields
- User focused communication
- Cooperation in teams

The normal way physics skills are achieved by physics students, is to learn a lot of different content, from kinetics, optics to quantum electrodynamics and much more. During the years of physics study the skills are acquired on the fly. For engineering students with only a few physics courses, the idea arises, whether it is possible to take a short-cut, by right away focusing on teaching physics methods instead of struggling with teaching physical content.

FROM TEACHING THE CONTENT TO THE TEACHING OF METHODS

Changes in the didactic context of "what will be taught" usually affect not only one single lecture course, but very often has an influence on a whole study program.

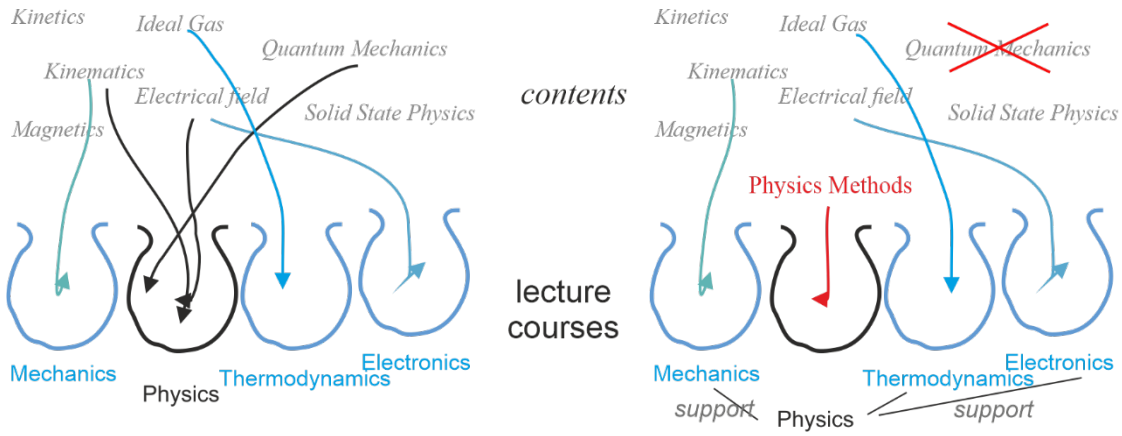

Fig. 3: Exemplary Rearrangement of Physics Content at the HTWG University Konstanz:
Left: Physics courses formerly covered content that was also taught in engineering classes.
Right: All "important" content is now taught solely in engineering classes. Some content was omitted. Physics courses have now the freedom to focus on "physics methods", with which engineering courses are supported. The physics content chosen, like kinematics, kinetics or thermodynamics, is used to transport physics methods.

At the process start, both physics and engineering courses sometimes had the same or strongly related topics. In discussions and workshops with colleagues from engineering disciplines, we derived a solution, where the important part of the content is now covered in engineering classes. Sometimes engineering lecturers even stated that they know better what students need, so they were very much satisfied with this switch in focus. Simultaneously the physicists had created a list of "important physics methods". Which methods and tools are the simplest and are most widely used? Which of those help students on their way to acquire physics-skills? Following methods were included:

- dimensions, units
- orders of magnitude, mental arithmetic
- uncertainty calculation
- reality - math - reality
- reduce complexity
- conserved quantities, balancing
- open questions
- change in perspective
- reporting
- creating and using diagrams
- reasoning
- estimating values for quantities
- looking for symmetries

This list is the result of many discussions between our physics lecturers. These are the methods we teach in our current lessons. If necessary, the list can be easily modified or extended.

What content is suited best?

Teaching methods without giving examples makes no sense. In order to reach the teaching goal, the next step was to find suited content. For this the order of fig. 2 was inverted: Starting from the desired skill, the supporting methods were determined. Thereafter we looked for content, where the methods show benefits when applied. This led to Table 1:

Table 1. Physics skills and methods. The table shows which methods can support certain skills. It also gives examples for content which can be used to forward and deepen methods. Two skills are included which are not of physics origin, but still addressed in our courses (below bold line).

Physics													
skills	methods & tools												exemplary content
	dimensions, units	mental arithmetic, order of magnitude	uncertainty calculatiopn	reality - math - reality	reduce complexity	conserved quantities, balancing	Fermi problems	change in perspective	reporting	diagrams	reasoning	looking for symmetries	
Mastering a full experimental cycle	x	x	x	x					x	x			lab experiments: moment of inertia, specific resistivity, ...
Moving from observation to theory				x	x	x	x				x	x	rotating boxes, angular momentum, Momentum transfer
Applying theory to problem solving	x	x		x	x	x							kinematics, kinetics
Approaching tasks				x	x	x		x				x	momentum transfer and forces
Dealing with complex systems					x	x	x				x	x	energy and climatic change
Reasoning		x				x		x			x		why does an airplane fly
Entering into unknown fields		x			x	x	x				x	x	QM, Qubits, Acoustics, Optics, ...
User focused communication	x	x							x	x			

This matrix helps to identify the methods needed to train skills (marked with an x in the table). It is also useful when looking for examples and content to be used during lectures.

Obviously one single exemplary piece of content can be used to teach multiple methods, and thus strengthen several skills simultaneously.

EXAMPLE: ENERGY IN A GRAVITATIONAL FIELD

The following example pictures our approach of "content-driven acquired method" teaching:

Exercise given in kinetics – potential energy:

How long does it take a car to move uphill (mass of 1.4 tons, motor with the maximum power of 80 kW) to a point which is 300 m higher?

Proposed solution:

$$P = \frac{\Delta E}{\Delta t} = mg\,\frac{\Delta h}{\Delta t} \Rightarrow \Delta t = \frac{m\,g\,\Delta h}{P} = 52.5\ \text{s}. \qquad (1)$$

The result is obtained using the values given with the help of a calculator.

Same exercise used for teaching "physics methods":

A car should drive up a hill. How long does it take to reach a place further up?

Each of the following steps describes one or more methods that can be taught with this example.

Step 1. Open Question and Dimensional Analysis:
Even if students do not recall basic equations like the one above, they should be capable of performing following steps:

- From reasoning they will assume that the car's mass *m*, the power of the motor *P* and the difference in altitude Δh will have an influence on the time needed.
- From dimensional analysis they find the missing variable, the gravitational field-strength g. Following this path, they will reach the equation:
  $\Delta t = \text{k}\,\frac{m\,g\,\Delta h}{P}$ with k being a dimensionless constant. (2)
- Hopefully they now remember the correct equation with k = 1.
- In the next step they make assumptions, for example m = 1.4 t; Δh = 300 m and P = 100 hp, (students sometimes use units "*tons* t" and "*horse-power* hp").

Step 2. Mental arithmetic, Units and Orders of Magnitude :
Knowing 1 hp is approximately ¾ kW. They will obtain:

$$\Delta t = \frac{1.4\ 10^3\ \text{kg}\cdot 10\ \text{m}\cdot 300\ \text{m}}{\text{s}^2\cdot 100\ \text{hp}} \cdot \frac{4\ \text{hp}}{3\ \text{kW}} \cdot \frac{\text{W}\cdot\text{s}^3}{\text{kg}\cdot\text{m}^2} \approx 1.4\cdot 10\cdot 4\ \text{s} \approx 55\ \text{s} \qquad (3)$$

Step 3. Reasoning: Does it make sense?
Assuming a slope of 10 % (which is already a steep road) will lead to a distance of 3 km. Driving this distance in less than a minute requires an average speed of over 50 m/s or almost 200 km/h!

Step 4. Accuracy: Difference between Correctness and Precision
This example shows the uselessness of the precision given in eq.1.

Step 5. From Observation to Theory, Applying Theory to Reality, Conserved Quantities:
Students now ask where this energy has gone. Since energy and momentum are conserved quantities, they must have disappeared to another system. Students should identify the air as the system that needs to be added.

Step 6. Dimensional Analysis: Momentum lost to air; drag force
Again using this method they obtain the equation for the wind resistance force F

$$F = c_W \varrho A v^2 \quad (4)$$

where c_W: drag coefficient, ϱ: air density; A: cross section area and v: speed between car and air.

Step 7. Balancing equation, for driving with constant speed
With the help of energy balancing they arrive at ($I_{E,i}$ denotes to energy-currents, Δv to the speed between car and road):

$$0 = \frac{\Delta E}{\Delta t} = \sum I_{E,i} = P - mg\,\dot{h} - c_W \varrho A v^2 \Delta v \quad (5)$$

which they can solve numerically, if needed.

This example shows how several methods can be learned at the same time with one content-related question. The students always learn to use several methods. When they later move on to other topics, these methods are used again. This gives the teaching-approach enormous power.

ADVANTAGES

After managing the transformation from teaching "content" to teaching "methods", all stake holders will benefit, because the physics-courses of various programs only differ in the engineering focus, application and content, like electrical, mechanical or civil engineering. They are alike in the essential part, the methods:

- Students have a faster way to acquire methods and train skills. Furthermore it is easier for them to switch study programs, if wanted.
- The heterogeneity of the students can be dealt with more easily. Our students have physics experience in school ranging from no-physic-at-all to several years up to almost undergraduate university level.
- Less resources are needed to run basic physics labs. Therefore less staff is required for support.
- Faculties are more flexible when planning physics courses. All physics courses are interchangeable.
- If lecturers want to go on a sabbatical, it is easier to find step-ins for their physics courses.

IMPLEMENTATION

For the implementation, an institute has been set up to promote teaching-innovations in the fields of science and mathematics. The whole process started about 20 years ago with one study program in mechanical engineering. Year after year it was slowly expanded, adding more programs and more faculties. Everyone was free to join. There was no "pressure" on anyone, neither financial nor from organization. Yet, more and more teaching staff joined this group until finally in 2023 all physics courses in all engineering faculties of our university are part of this concept.

Also in 2023 a textbook "Physik Methoden" [8] has been published which is now used as main lecture note. This book describes the basic ideas and the implementation of how methods learning can work. In 12 chapters, each focused on a physics-method, it provides instructions for students and lecturers. The chapters are suitable as learning texts for flipped classroom approaches.

CONCLUSION AND OUTLOOK

Teaching physics methods is possible, as proven over the last years at HTWG Konstanz. It however needs good examples. Therefore we call the concept “content-driven acquired methods” teaching. This concept has been developed especially for physics teaching in engineering education. There are benefits for all parties in the learning process, students, staff, faculties and lecturers.

The process has now reached a point where the whole university physics teaching is involved. We will further develop the settings and improve the courses. Especially it is intended to compare the learning achievements of students using “content driven acquired skills” teaching to a more classical physics teaching approach.

It takes time to perform the transformation to teaching “methods”. But it can be done in small steps, with steady progress. There is no need to hurry. Any university and lecturer may choose their own pace.

And probably the most important of all. Students have acquired several skills by the end of the courses. This can be seen in the final exams, where method based questions are posed. Students are able to solve those, and grades tend to be better.

We started this 20 years ago, and it works!

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USING RESEARCH-BASED INSTRUCTIONAL MATERIALS TO FOSTER CONCEPTUAL UNDERSTANDING – *TUTORIALS* IN INTRODUCTORY PHYSICS

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Research on the teaching and learning of physics has identified specific conceptual and reasoning difficulties that often prevent students from developing a functional understanding of various topics taught in introductory physics courses. There is evidence that instructional materials that take into account such difficulties and prompt students to critically assess their own understanding can improve student learning. In this paper *Tutorials in Introductory Physics* are introduced, a set of materials intended to supplement the lecture, textbook, and laboratory of standard introductory physics courses for students in physics, engineering, and other fields. The *Tutorials in Introductory Physics* were originally developed by Lillian McDermott and the Physics Education Group at the University of Washington. They have been translated into other languages, including Spanish, Greek and German. In addition, they have served (and continue to serve) as a model for the development of instructional materials for other STEM subjects, such as electric circuits and engineering mechanics. We discuss various aspects of incorporating the *Tutorials* into a typical course and possible issues associated with their implementation.

Keywords: Teaching Physics, Tutorials in Introductory Physics, Conceptual Understanding

INTRODUCTION

For more than 25 years, a set of instructional materials for (mostly) first-year physics courses – the *Tutorials in Introductory Physics* [1] – have been available from a major US publisher and have been used at various colleges and universities throughout the United States. Their effectiveness in helping students develop a sustained, functional understanding of the pertaining concepts, i.e., an understanding that can be transferred to unfamiliar problem settings, has been shown in a number of studies published in journals like *American Journal of Physics* and *Physical Review.* However, the use of these materials in Europe, be it in the English original or in a translated version (e.g., to German, Greek or Spanish) is not very widespread. This holds true even in light of demonstrated evidence that solely introducing activating methods into (traditional) lectures is not associated with student learning [2].

What are *Tutorials*?

Tutorials are guided inquiry worksheets that engage students in a Socratic dialogue (e.g., [1], [3], [4], [5]) in order to help them overcome known widespread difficulties with the concepts of physics. They are intended for in-class use (see below) in combination with pretests, homework assignments and post-tests [6]. Key features of the *Tutorials* include their research-based development [7], [8], their subject-specific and methodological objectives, as well as how they are implemented in instructional sessions as group activities (see [9] p. 9-16).

Aim of the article

The aim of this article is to inform instructors of Physics about the availability of these materials, to give some important guidelines for their implementation, and to discuss possible problems that may occur during implementation (and how to overcome these). We will not discuss here the research base underlying their development or assessing their effectiveness. We refer the reader instead to other publications (see the *Appendix* at the end of the article). That list, as well as some of the ideas and observations expressed in this article, have been previously published in German in a recent issue of *Physik Journal*, the official journal of the *Deutsche Physikalische Gesellschaft* [10].

Motivation for and objectives of instruction using *Tutorials*

The decision to use *Tutorials* should be based on the learning goals that the instructor defines for the course. If they include a deep conceptual understanding of certain fundamental concepts, the *Tutorials* provide an adequate means to obtain these goals, whereas traditional instruction is not successful in doing so for the majority of students. The causes for this failure are diverse; a significant reason is the difficulty of the physical concepts themselves, which can lead to widespread, systematically incorrect perceptions (misconceptions) among learners [7].

Consequently, *Tutorials* "guide students through the reasoning necessary to construct concepts and to apply them in real-world situations" [6]. *Tutorials* often use a method referred to as "elicit-confront-resolve" [11] to elicit misconceptions, confront students with them and finally help students resolve them. This occurs through, for example, thought experiments, hypothetical student statements, or small physical experiments. Thereby, students are also expected to "learn to ask themselves the type of questions necessary to come to a functional understanding" [6] of physics.

SELECTION OF *TUTORIALS* FOR PHYSICS COURSES

Choosing a set of *Tutorials* for a given course should be determined, first of all, by the learning goals to be achieved and the specific difficulties to be addressed. However, many topics in physics are interconnected. For example,

- students must be able to differentiate between velocity and acceleration and understand both quantities as vectors, before a conceptual understanding of forces is possible.
- forces have to be understood as the interaction of two bodies and only then Newton's second and third law can be addressed.
- the ideal gas law must be understood before the first and second law of thermodynamics can be addressed, especially the distinction between temperature, internal energy and heat.
- the concepts of a complete circuit as well as the conservation of charge and current have to be understood before *Tutorials* using the concept of voltage can be used.

Therefore, the necessary foundations need to be laid first with the corresponding *Tutorials*.

Whether the selected *Tutorials* are suitable for the students' level can, in part, be assessed based on the average completion time of the worksheets: if students finish significantly faster than expected, a given *Tutorial* may raise issues that are not problematic for these particular students; if they need much more time than allotted, the topic may be too challenging for them. Especially if already the first page of the worksheet requires a disproportionate amount of time, this may also lead to frustration on the part of the students, thereby further limiting students'

progress. Other indicators for the appropriateness of a particular *Tutorial* are the quality of the questions and discussions among the students.

THE ROLE OF THE *TUTORIAL* INSTRUCTORS

Tutorials are not intended for self-study, but should be worked on by the students during class-time, as group work, and supported by teaching staff. Here, we refer to the instructors in a *Tutorial* setting as learning assistants, a term that has been used by others in this context (but referring mainly to undergraduate students in this role) [6], [12]. Their responsibility is, first of all, to listen to the students' group discussions and analyze the ideas being exchanged. If necessary, they then pose questions to (1) prompt the students to rephrase their ideas in a more precise way, (2) reconsider the task to be solved at the moment, or (3) to help them analyze each other's arguments in order to differentiate incorrect assumptions or conclusions from correct ones [6].

Depending on their prior experience with the *Tutorial* worksheet in question (and with teaching physics in general), the learning assistants will need more or less preparation. However, even very experienced instructors will need to familiarize themselves with the specific learning goals incorporated in the particular worksheet and with the way in which these are expected to be achieved. For student teachers or other newcomers to this Socratic style of teaching, a weekly preparatory session strengthens understanding of content and pedagogy, including pedagogical content knowledge, i.e., the understanding of how a particular topic is difficult for students and how the difficulties can be addressed. During these meetings, the learning assistants work in small groups through the same material and discuss the logical steps that students need to go through [6].

The role of the *Tutorial* instructors is not to provide solutions to the students. The *Tutorials* are only effective in helping students develop a thorough understanding of the relevant physics concepts if the students work through the worksheets themselves. Since it is unlikely that the students have a complete understanding of all the concepts at the outset in most cases, this includes making mistakes. Students are often able to correct these mistakes by themselves or with some minimal help from the learning assistants.

For the same and other related reasons, no sample solutions are provided by the authors, and no self-written solutions should be handed to the students by other instructors. Going through the process of finding answers is necessary not only for understanding the subject matter (and appreciating the subtlety of some of the physics concepts), but also for reaching most of the other learning outcomes, including the ability to probe one's own understanding, to construct a sound logical argument using hypothetico-deductive reasoning, to express one's thinking about physics verbally, and to trust the results that the group has arrived at. Other adverse effects of the availability of sample solutions could be that alternative (but correct) ways of reasoning might not be recognized. Finally, the motivation to go through a sometimes strenuous reasoning process may be undermined if students know that sample solutions are available.

IMPLEMENTATION OF *TUTORIALS*

In order to support student "buy-in", we consider it essential that some measures are taken before or during the first *Tutorial* meeting that help students understand the purpose of working with *Tutorials*. We have found that such measures are more likely to be successful if they include a student activity (e.g., students thinking about how they learn best) and that they can

easily be combined with measures to "advertise" other active-learning elements in the course (such as *Peer Instruction* or *Just-in-Time Teaching* [13], [14], [15], [16]).

Aiming for the general goal that intended learning outcomes, examinations, and classroom practices form a consistent whole (often referred to as *Constructive Alignment* [17], [18]), course examinations should contain tasks or questions that are similar to the *Tutorial* tasks in both type and style, avoiding, of course, the use of identical questions. This also helps in convincing the students to take the *Tutorial* instruction seriously, as some students may not do so immediately [6].

The *Tutorials* are not intended to replace the presentation of the subject matter in a textbook or lecture, nor the solving of typical (often computationally challenging) exercises. Instead, their aim is to build a solid conceptual understanding. Standard (quantitative) 'end-of-chapter' type problems therefore may still be used alongside the *Tutorial* worksheets and related homeworks, but possibly in a reduced amount, in a separate class meeting in larger groups, or (digitally administered) moved to self-study periods ([6], [9]) while keeping the overall student workload in mind. Studies indicate a significantly higher effectiveness of instruction when utilizing *Tutorials* compared to traditional teaching, even when the total class time remains the same [12], [19], [20].

Implementation in class sections of <25 students

At universities that teach introductory subjects in large lecture sections of 50 students or more, the *Tutorials* are often taught in smaller recitation sections on the order of 25 students. In this case, the lectures may continue to use whatever format they used before [6].

For the specific layout of the *Tutorial* sections, groups of four students seem most practical in many situations and form a good compromise between 'small enough' for active participation of *all* group members and a manageable number of groups in one room. (Even just one additional student in our experience often leads to one or more of the group members dropping out of the discussions.) The four students in each group should face each other pairwise across a table that is not too wide to allow simultaneous interaction with shared artifacts, including a large (A3) sheet of paper or similar size whiteboard that serves as a 'hub' for the group on which their discussion is focused. The separation of neighboring groups should be large enough to discourage students from interacting with the other group and to allow learning assistants to access each group easily.

We recommend a student-instructor ratio of no more than 24:1, requiring one learning assistant to interact with a maximum of six groups. Even in that case, the presence of a second learning assistant is desirable and worthwhile, especially if one of the two is relatively inexperienced in using *Tutorials* or if the knowledge and skills of the student groups are very diverse. Even very experienced instructors often appreciate the possibility to either take time to simply observe or to exchange observations or ideas with each other during a *Tutorial* session.

Some of the *Tutorials* require or strongly recommend the use of small experiments. These can be included more easily in the tutorial session in this setting.

Implementation of *Tutorials* in larger sections

The *Tutorials* have also been used successfully in large courses, with as many as 450 students in one room. If the setting is that of a theater-style (sloped) auditorium with rows of fixed seats, we encourage students to form groups of three so all members of one group can still communicate easily with each other. Every second or third row should then be left unoccupied, if the numbers permit this, to allow the learning assistants to reach every group in the room. In

this case, a somewhat higher student-instructor ratio is possible. For us, about 12 learning assistants helping 450 students has worked quite well.

POTENTIAL ISSUES DURING IMPLEMENTATION AND THEIR SOLUTIONS

When first implementing the *Tutorials* in an existing course, instructors often run into problems. We discuss some of the common ones and make suggestions on how to address them.

Not enough time to complete the *Tutorial* worksheets

The reasons why students may fail to complete a worksheet in the time given to them include (1) that the *Tutorials* are too difficult given the students' level of preparation, (2) that students are distracted during the course, or (3) that students misinterpret some questions, e.g., regarding the depth intended, or are not used to the way in which the questions are posed. In the case of (1), there is a good chance that substantial learning occurred nevertheless, but students may have spent considerable amounts of time building an understanding of subject matter that was considered a prerequisite and therefore were lacking time to spend on the truly "new" concepts. Choosing a different *Tutorial* for the following year or including a *Tutorial* that covers those prerequisites might improve the situation. (Even then, not all students will finish a given *Tutorial*. If they did, with any spread in the students' abilities in the class, a substantial number of students would finish early and be bored or leave the class.) If (2) is the reason for the time issues, simply interrupting off-topic conversations may not be sufficient as students may need to be reminded (and convinced) of the relevance of the *Tutorial* worksheets. Reason (3) will, from our experience, usually be resolved within the first two to four *Tutorial* sessions as students get used to the way the *Tutorial* tasks are worded. Depending on students' overall experience with group worksheets or other active-learning formats, more than the intended 50 minutes per Tutorial will be needed.

Low willingness of students to work on the *Tutorials*

For many students, to reason carefully and step-by-step about a given question, instead of relying on their first impulse with respect to the answer, is a new experience when coming to university. This activity may therefore feel unpleasant and not worth the effort. Adjusting to this (scientific) way of reasoning can be made easier for the students by carefully choosing the *Tutorials* to be worked on. They should neither be too difficult nor too easy for the average student, so that the students gain self-confidence about their abilities. Implementing an atmosphere in the course, among students *and* instructors, where failure is seen as an aspect of learning (and not an impediment to it) is crucial. This can be achieved, for instance, by refraining from very negative phrases such as "this is wrong" and instead posing questions that prompt students to recognize mistakes in their thinking on their own. The learning assistants should embrace mistakes and encourage the students to learn from them since failure is often a necessary step in the development of conceptual understanding.

Doubts about the *Tutorials* on the part of the instructor concerning usage and outcomes

Problems during a first implementation of the *Tutorials* are not uncommon and may give rise to serious doubts on the part of the instructor about the value of using them. This may be exacerbated if exam results do not immediately show improved learning or if course evaluations even deteriorate. However, whether the gain in knowledge and deeper understanding leads to better results in the exams or in evaluations depends on various factors. Are the exams aligned with the learning goals and do they test for understanding and not only calculational skills? Do the evaluations prompt students to reflect on their learning or do they simply ask whether

students "liked" the course? As a result of such possible misalignment, a gain in understanding can often not be seen in these data.

While it is important for instructors to be alert to problems during implementation, they should also not be overestimated. Some problems seem bigger than they are and can be overcome through small adjustments to the implementation or will disappear as students (and instructors) get used to the process. In assessing whether an observed problem needs immediate attention or whether it can be dealt with at a later time, some guidance from an instructor experienced with using *Tutorials* can be very valuable and, in addition, usually helps to dispel doubts and renew the motivation to use the materials.

CONCLUSIONS

The implementation of the *Tutorials in Introductory Physics* within an existing physics course is a worthwhile modification that does not involve a complete re-design of the course (as might other active-learning innovations). However, it does require some minor adjustments to the course and, most importantly, the willingness of the instructor to persist even if some initial problems occur. The authors of this article, as well as many other instructors who use the *Tutorials*, have found this a worthwhile endeavor that not only helps improve their students' understanding of physics but also positively changes their perceived role as a teacher.

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APPENDIX: OVERVIEW OF PUBLISHED PRE- AND POST-TEST DATA

In the context of individual *Tutorials* (from the '*Physics Tutorials*'), sorted by topic:

Mechanics

- Two-dimensional kinematics:
  Shaffer, P.S., McDermott, L.C., 2005. A research-based approach to improving student understanding of the vector nature of kinematical concepts. American Journal of Physics 73, 921–931. https://doi.org/10.1119/1.2000976
- Dynamics of rigid body:
  Close, H.G., Gomez, L.S., Heron, P.R.L., 2013. Student understanding of the application of Newton's second law to rotating rigid bodies. American Journal of Physics 81, 458–470. https://doi.org/10.1119/1.4797457
- Equilibrium of the rigid body:
  Ortiz, L.G., Heron, P.R.L., Shaffer, P.S., 2005. Student understanding of static equilibrium: Predicting and accounting for balancing. American Journal of Physics 73, 545–553. https://doi.org/10.1119/1.1862640

Hydrostatics and thermodynamics

- The hydrostatical pressure:
  Loverude, M.E., Heron, P.R.L., Kautz, C.H., 2010. Identifying and addressing student difficulties with hydrostatic pressure. American Journal of Physics 78, 75–85. https://doi.org/10.1119/1.3192767
- Buoyancy:
  Heron, P.R.L., Loverude, M.E., Shaffer, P.S., McDermott, L.C., 2003. Helping students develop an understanding of Archimedes' principle. II. Development of research-based instructional materials. American Journal of Physics 71, 1188–1195. https://doi.org/10.1119/1.1607337
- Ideal gas law:
  Kautz, C.H., Heron, P.R.L., Loverude, M.E., McDermott, L.C., 2005. Student understanding of the ideal gas law, Part I: A macroscopic perspective. American Journal of Physics 73, 1055–1063. https://doi.org/10.1119/1.2049286
- The particle model of the ideal gas:
  Kautz, C.H., Heron, P.R.L., Shaffer, P.S., McDermott, L.C., 2005. Student understanding of the ideal gas law, Part II: A microscopic perspective. American Journal of Physics 73, 1064–1071. https://doi.org/10.1119/1.2060715
- First law of thermodynamics:
  Loverude, M.E., Kautz, C.H., Heron, P.R.L., 2002. Student understanding of the first law of thermodynamics: Relating work to the adiabatic compression of an ideal gas. American Journal of Physics 70, 137–148. https://doi.org/10.1119/1.1417532
- Heat engines and second law:
  Cochran, M.J., Heron, P.R.L., 2006. Development and assessment of research-based tutorials on heat engines and the second law of thermodynamics. American Journal of Physics 74, 734–741. https://doi.org/10.1119/1.2198889

Electricity and magnetism

- A model for electrical circuits:
  Shaffer, P.S., McDermott, L.C., 1992. Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. American Journal of Physics 60, 1003–1013. https://doi.org/10.1119/1.16979

Oscillations and Waves

- Electromagnetic waves:
  Ambrose, B.S., Heron, P.R.L., Vokos, S., McDermott, L.C., 1999. Student understanding of light as an electromagnetic wave: Relating the formalism to physical phenomena. American Journal of Physics 67, 891–898. https://doi.org/10.1119/1.19144

Optics

- Geometric optics:
  Wosilait, K., Heron, P.R.L., Shaffer, P.S., McDermott, L.C., 1998. Development and assessment of a research-based tutorial on light and shadow. American Journal of Physics 66, 906–913. https://doi.org/10.1119/1.18988
- Wave optics:
  Wosilait, K., Heron, P.R.L., Shaffer, P.S., McDermott, L.C., 1999. Addressing student difficulties in applying a wave model to the interference and diffraction of light. American Journal of Physics 67, S5–S15. https://doi.org/10.1119/1.19083

Selected topics of modern physics

- Relativity:
  Scherr, R.E., Shaffer, P.S., Vokos, S., 2002. The challenge of changing deeply held student beliefs about the relativity of simultaneity. American Journal of Physics 70, 1238–1248. https://doi.org/10.1119/1.1509420
- Wave properties of matter:
  Vokos, S., Shaffer, P.S., Ambrose, B.S., McDermott, L.C., 2000. Student understanding of the wave nature of matter: Diffraction and interference of particles. American Journal of Physics 68, S42–S51. https://doi.org/10.1119/1.19519

Studies of the long-term effects of Tutorials include:

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- J. Direnga, “Assessing the effectiveness of research-based active learning materials for introductory engineering mechanics,” Hamburg University of Technology, 2021. https://doi.org/10.15480/882.3229

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RETHINKING CLASSICAL MECHANICS FOR ENGINEERING UNDERGRADUATES: A HANDS-ON APPROACH TO OSCILLATIONS AND WAVES

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Physics lectures for engineering students are often given in a canonical order and using a traditional lecture format which might not always be the best choice. In this article we present a restructured curriculum that focuses on the understanding of oscillations and waves and enriches lectures with hands-on experiments and tutorials.

Keywords: physics curriculum, hands-on experiments

INTRODUCTION

Physics lectures for undergraduate students are typically structured in a traditional way: They start out with a discussion of Newtonian kinematics and dynamics in one or two dimensions and progress through topics like energy, momentum and rigid body dynamics. This approach, while foundational, has some shortcomings when teaching non-physics majors.

Classical mechanics, while necessary for the understanding of more advanced concepts, has limited direct relevance in engineering subjects such as Information Technology which makes it hard to present students with applications relevant to their field of study. Inclusion of more advanced topics like oscillations and waves or even modern physics is often difficult due to time constraints as it leads to an over-full curriculum and, consequentially, to a lack of depth in the topics discussed. Thus, physics teaching in tertiary education is usually structured classically. Being a repetition of the same concepts of secondary education context and only differing in the presented methods and depth, the lecture is perceived as boring and as a setback especially by good (and initially motivated) students.

Starting from this premise we restructured our first semester physics curriculum focusing on a deep understanding of the properties of oscillations and waves, topics particularly important to students of Information Technology. Necessary concepts from classical mechanics are taught specifically in the context of oscillations and waves. A special focus is given to dedicate at least one third of the available time to active learning methods [1-3] such as hands-on experiments, tutorials [4] and group exercises with calculation problems and peer-instruction [5] to discuss central but crucial concepts such as driven oscillations, resonance or wave impedance in order to facilitate a deeper understanding of these concepts. In contrast to the SCALE-UP concepts promoted by e.g. Beichner et al. [1], all sessions including the hands-on experiments were limited to being carried out in a tiered lecture hall. The course presented in this paper comprises of 14 weeks with three times 90 minutes of lecture time per week. The course was given for the first time in the fall term 2023/24 to two independent groups of students (about 35 and 50 students, respectively) at the department of Information Technology at Mannheim University of Applied Sciences.

CURRICULUM

The curriculum was developed looking for a good balance between highly relevant topics for the students' field of study and seemingly boring but needed physics background. Wherever possible, examples are chosen according to the students' field of study. For a start, the following structure was tested:

1. Introduction
   1.1. Relevance of Oscillations and Waves in Information Technology
   1.2. Physical Quantities and Units
2. Kinematics of the Oscillation
   2.1. Kinematics in One Dimension
   2.2. Motion of the Free Harmonic Oscillator
3. Dynamics of the Oscillation
   3.1. Newton's Laws of Motion
   3.2. Free-body Diagrams
   3.3. Differential Equation of the Free Harmonic Oscillator
   3.4. Complex Pointer Representation and Superposition
4. Energy Balance of Oscillations
   4.1. Work and Energy
   4.2. Energy Balance of Oscillations
5. Damped Oscillations
   5.1. Friction
   5.2. Damped Harmonic Oscillations
6. Driven Oscillations and Resonance
7. Waves
   7.1. Wave Function of the Harmonic Wave
   7.2. Physical Quantities of Different Mechanical Waves
   7.3. Standing Waves
   7.4. Doppler Effect

For orientation, we provided students with a commented curriculum: For each section the learning goals, specific references to textbook chapters, the relevant exercises and the most important experiments were listed.

HANDS-ON EXPERIMENTS AND TUTORIALS

While most of the concepts presented are illustrated using demonstration experiments within the lectures, some concepts are especially challenging for students and require more discussion. From our experience with prior courses the following topics were identified as

especially challenging: Motion diagrams, forces and free-body diagrams, formulating differential equations for (harmonic) oscillators, driven oscillation and resonance, and wave impedance. For those topics it was decided that in addition to lectures more active teaching formats like tutorials [4] and hands-on experimentation in groups of up to 5 students should be employed to facilitate the students' learning experience [2,3]. Where possible we adapted existing ideas, e.g. for the discussion of motion diagrams [4] and free-body diagrams [4] while we designed the experiments for driven oscillation and resonance in harmonic oscillators (E1) and for wave impedance (E2) ourselves.

The hands-on experiments were designed in such a way that they discuss the specific topic through a series of small experimental tasks. The whole experiment with all tasks and discussions should not take longer than one lecture block of 90 minutes. The experimental setup should consist only of commonly available (i.e. cheap and easy to get) materials and the experiment can be built and carried out in a standard, tiered lecture hall with fixed tables. While most experimental tasks focused specifically on qualitative observations small quantitative measurements where included where possible.

The primary learning goal of E1 is a qualitative understanding of the relation between the driving frequency of the pendulum and its oscillation frequency, its amplitude and its phase shift with regard to the driving force. To approach this goal, a simple pendulum was constructed by the students from a piece of string of $l \approx 30$ cm length with an M10 nut attached to one end.

In a first step students were asked to measure the eigenfrequency of the free pendulum and compare it to the theoretical value derived in an earlier group exercise. They were then asked to drive the pendulum by a small horizontal motion of the hand holding the string with various frequencies starting from about 10 % and up to a factor of two times the eigenfrequency. To ensure a consistent motion a metronome app set to the desired frequency gave an audible rhythm. Students were tasked to observe the amplitude, the frequency and the phase shift relative to the driving force for each driving frequency and estimate the relative change from frequency to frequency. Results should be sketched in diagrams of amplitude versus driving frequency and phase shift versus driving frequency.

There are two main learning goals for E2. On the one-hand students should gain experience for the different influences on the wave propagation and address common misconceptions such as the nature of a wave pulse or the influence of the excitation amplitude [6]. On the other hand, the seemingly abstract but to Information Technology strongly relevant concept of wave impedance should be made tangible.

To address these goals a simple transversal wave machine was constructed by the student groups using a 2 m strip of duct tape with wooden shashlik sticks as oscillators attached to the tape at regular intervals, see Fig. 1. The tape acts as a torsion spring and provides coupling between the individual oscillators. Gummy bears are placed on both ends of the sticks in order to increase the moment of inertia of the individual oscillators. A second layer of tape is attached from the top for stability reasons. Similar designs can be found online [7].

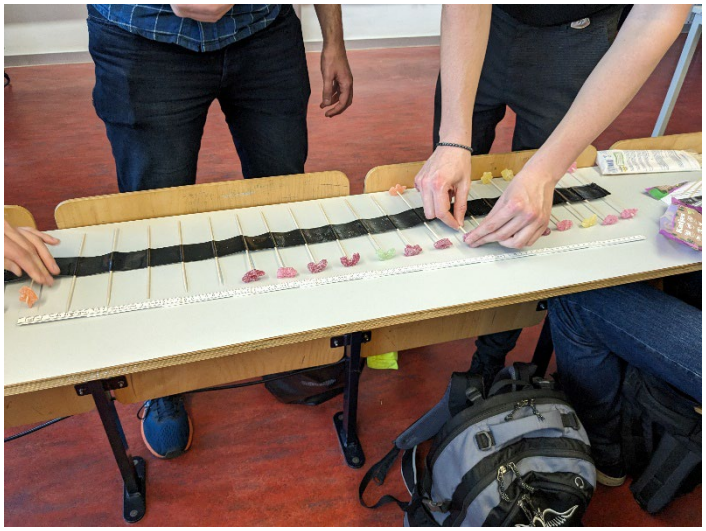

Fig.1. Construction of a wave machine in progress

The properties of this wave medium can be adjusted in a couple of ways. More tension in the tape provides greater torque to the individual oscillators while adjusting the position of the gummy bears leads to different moments of inertia, thus providing different wave impedances for the whole medium or for parts of the wave machine.

First, the students were tasked to excite wave pulses on the machine and observe the dependence of the propagation speed on the tension of the tape and the position of the gummy bears. They were also asked to observe the behavior of the pulses on both ends of the wave machine were reflections are taking place. Discontinuity of the wave medium was simulated by placing the gummy bears in one half of the wave machine on the outer ends of the sticks while in the other half of the wave machine they were placed right next to the tape. Students were asked to discuss the behavior of the pulses on the boundary between the two halves and find a solution for the partial reflection of the pulses, leading naturally to impedance matching, c.f. Fig. 2.

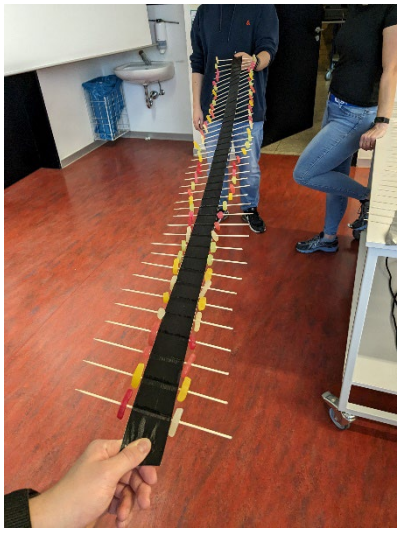

Fig.2. Completed wave machine set up for the demonstration of impedance matching

RESULTS FROM COURSE EVALUATION

Students were asked to evaluate the new course elements as part of the overall course evaluation at the end of the semester. The evaluation was carried out ad libitum and anonymously via an online questionnaire in moodle. N=41 Students out of about 85 that participated in the subsequent exam evaluated the lecture. The students came from two different courses (N=19 and N=22 respectively) given by different lecturers, therefore some accounting for different teaching styles is given. There is, however, no significant difference between the two groups observable in the data. Some percentage of students (about 20%) repeated the course due to a previously failed attempt and have therefore experienced a more classical curricular structure in the past.

Some of the questions and answers concerning the new course structure is summarized in Table 1. Overall, the majority of students found that the new course had a consistent and motivating structure and that they benefited from the hands-on experiments. This is consistent with our observations in the classroom, where we perceived especially the more active course elements as benefitting with regards to the overall learning process of the students. All students engaged actively in physics discussions during group work including those that were less active during classical lecture periods. During the wave machine session, several students spontaneously shared their thanks for this lively and descriptive experience.

Additionally, we asked students about the perceived relevance of the physics topics discussed to their field of study, as this is a recurring theme when discussing the need for physics education for engineering students with students and colleagues with an engineering background alike. The great majority of the students (about 78%) perceived relevance of the lecture content to their field of study as clearly identifiable or identifiable, while only 17% answered that they could see only little or no relevance at all (no answer 5%).

The great majority of 83% would prefer the course given in the same way again rather than in a more classical approach if they were given the choice. Whether this is mainly due to the changed curriculum or to the increased use of active teaching methods is not easy to evaluate. While it is surely possible to implement more active learning methods without changing the curriculum, in our case, only the change in the curriculum gave room to more in-depth discussions and an intensified use of active learning methods concerning the topics relevant to the students' field of study.

One point of interest is the students perceived learning success in the course. Students are asked to rank their perceived success on a five-point scale equivalent to the German grading system from very good to insufficient. Fig. 3 shows the results from the two courses given in the new format. Students report an overall good perceived learning success. While this question is part of the overall course evaluation that is being performed every semester, the results cannot easily be compared to answers from different student populations. Moreover, from the literature it is unclear if perceived learning success is a good variable for lecture evaluation as it seems to correlate with the perceived effort but not with the actual learning success of the students [8]. Given the high variability in the students' responses and the difficulty in controlling confounding variables such as variations in students' educational background between different student populations, more research is needed to draw conclusions.

Table 1. Results from course evaluation

	comprehensible	rather comprehensible	less comprehensible	not comprehensible	no answer
The structure of the lecture was …	31	8	0	1	1
	educational	rather educational	less educational	not educational	no answer
The hands-on experiment concerning driven oscillations was …	19	12	9	0	1
	educational	rather educational	less educational	not educational	no answer
The hands on experiment concerning wave impedance was …	15	9	5	1	1
	motivating	rather motivating	less motivating	not motivating	no answer
The structure of the lecture with an emphasis on oscillations and waves was - compared to a more traditional structure	15	22	4	0	0

Fig.3. Perceived learning success of students

OPEN QUESTIONS AND FURTHER IDEAS

The exam results showed that most students still had major difficulties to formulate a correct differential equation of motion by using free-body diagrams even for a simple set-up with two springs. To address this topic, we will add an additional tutorial session using the tutorial "harmonic oscillations" [4]. As the students had great fun with the experiments while struggling with interpretation and calculation, an additional experiment for the Doppler effect could be added to the curriculum, e.g. basing on the phyphox set-up with a smartphone on a pendulum [9,10]. Ideally, in future every larger topic will include a tutorial or experimental session as well as a session with group exercises (calculation problems and peer instruction [5]). Hands-on experiments and tutorials would be even easier to implement in a setting like a scale-up room [1]. Unfortunately, this setting conflicts limited resources and large course sizes currently found at many universities.

CONCLUSIONS

Overall, our experiment to use a restructured curriculum with more focus on slightly advanced topics using a hands-on approach showed some relevant points of success:

During the hands-on experiments all students engaged in vivid discussion about physics – independent from their regular behavior in classroom. While outwardly discussing the more complex but new concepts like wave impedance, students started to delve deeper into the underlying basics like e.g. the eigenfrequency of a free oscillator, as the discussions quickly turned to the basic physics behind the observed phenomena. This indicates that students gain a deeper understanding than during other lectures – which was the main goal of our teaching intervention. We expect students to dive into the physical backgrounds more easily once they experienced such discussions.

The stronger focus of the curriculum on more advanced topics right from the beginning, did not lead to any complaints about the increasing level of difficulty throughout the course, which were not uncommon in the more classical structure. One can assume that students could indeed see more relevance for their field of study in the restructured curriculum and thus were also willing to tolerate more difficult topics.

At least in the course evaluation most students opted for the adapted course compared to a course with a classical curriculum. As also we as lecturers enjoyed these discussions much more than the usual scarce questions during demonstration experiments, future plans are to intensify and promote the use of hands-on experiments even in settings with larger student groups in tiered lecture halls.

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LITHOGRAPHY CHALLENGES FOR PHYSICS AND ENGINEERING STUDENTS TO BECOME COMPETENT, SKILLFUL MICROTECHNOLOGISTS FOR THE SEMICONDUCTOR INDUSTRY

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Lithography is the workhorse for the global semiconductor industry. At the Applied Physics department of our institute, we have developed course-based projects in which we train physics students lithography skills that are valuable for a career in Europe's growing semiconductor industry. In this article, I will present the lithography facility at our institute, where students develop lithography processes for the fabrication of microstructures. I will show two examples of lithography projects that provided students the opportunity to grow towards competent, skillful lithographers. I will stress that universities of applied sciences in Europe need microtechnology facilities and competence centres that are embedded in Europe's semiconductor ecosystem to power the workforce for its industry growth.

Keywords: semiconductor industry, microtechnology competence, lithography skills.

INTRODUCTION

The semiconductor chip industry is one of the most valuable industries in the US, Asia and Europe. Politicians all over the world have identified that this industry is strategically important because it provides economic and geopolitical power [1]. The Semiconductor Industry Association (SIA) announced that the worldwide market of the semiconductor chip industry equaled more than $500 billion in 2023 [2]. Nowadays, roughly 80% of all chips are manufactured in Asia, while only 12% are produced in the US and 8% in Europe. Since Asia is dominating the semiconductor market, the European Union (EU) as well as the US have prioritized to strengthen their positions in the chip industry by aiming for an increase of their global market shares [3, 4].

Moreover, the demand of electronic chips is expected to double this decade due to rapid developments in, for instance, artificial intelligence (AI), communication networks (5G/6G), large-scale data centres, and the energy transition. Therefore, Ursula von der Leyen (chairman of the EU) announced in 2022 the so-called 'European Chips Act' to reinforce the chip industry in Europe, and to become less dependent on chip production in other continents [4]. Consequently, an important strategic objective of the EU is human capital growth for the semiconductor industry and the corresponding supply chain. Europe urgently needs competent microtechnology engineers and highly skilled lithographers to unlock the growth of a more autonomous semiconductor ecosystem in Europe. An important question is: *"how can Universities of Applied Sciences in Europe contribute to the European Chips Act?"*

In this article, I will present how we, at our institute THUAS in Delft, provide project-based hands-on laboratory trainings on microtechnology for physics and engineering students. The students work on dedicated lithography projects, in which they learn to deal professionally with the complexity of microfabrication processes: from design, lithography and patterning to inspection, metrology and electronic testing. The focus is on transferrable engineering skills that are relevant for micro-/nanotechnological R&D institutes as well as advanced high-tech

industries (e.g., ASML in The Netherlands, which is a key-player in the global semiconductor industry [5]).

This article starts with an introduction of the key-drivers for advanced lithography for chip fabrication in the semiconductor industry. Then, I describe the lithography and patterning processes on which students work in the microfabrication laboratory MICROFAB in our institute. I will explain why the professional competences and skill sets, which the students develop in their projects, are valuable for a career in the semiconductor high-tech sector. This article finishes with a discussion about how universities of applied sciences can contribute to the 'European Chips Act'.

ADVANCED LITHOGRAPHY IN THE SEMICONDUCTOR INDUSTRY

The semiconductor industry produces chips that are mainly based on silicon wafers (Fig. 1). Chip performance depends in general on the number of transistors per cm^2. Chip manufacturers like TSMC in Taiwan, Samsung in South Korea, and Intel in the US continuously push their technologies to achieve high-volume manufacturing of smaller high-performance transistors. Since more than half a century, the number of transistors per cm^2 doubles each two years, which is commonly known as Moore's law [6]. Downscaling of the smallest structures in transistors essentially depends on advances in lithography and patterning from one technology node to the other (i.e., currently from the '5 nm node' to the '3 nm node').

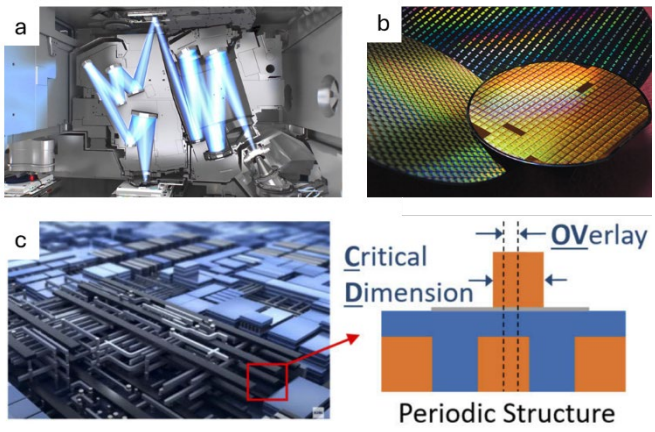

Fig.1. (a) Schematic picture of the EUV light path in the EUV lithography machine of ASML. (b) Chips on processed wafers. (c) CD and OV are imporant KPIs for lithography and patterning processes in the chip industry. Pictures adapted from [7-9].

The Dutch company ASML, which is considered as Europe's most valuable tech-company [5], is market leader in lithography machines for chip manufacturing. ASML's newest optical lithography machine is a so-called high-NA EUV machine, which uses extreme-ultraviolet light with a wavelength of 13.5 nm and optics with a high numerical aperture of 0.55 [10]. ASML's newest machine enables chip manufacturers to produce smaller transistors, and thus, more transistors per chip (Fig. 1a-b). This lithography machine should help the semiconductor industry to reach future technology nodes – as described in the International Roadmap for Devices and Systems [6].

In general, the smaller the images that can be generated by a lithography machine, the smaller the transistor patterns that can be produced. However, the smallest transistor sizes that can be fabricated do not only depend on the imaging resolution of a lithography machine, but also on the image alignment accuracy of the machine. As shown in fig. 1c, transistors are built

of different material layers that are accurately stacked on top of each other (like floors in a tall building). Two important key-performance indicators (KPIs) of a fabrication process are (1) the critical dimension, CD, which is the smallest feature size that can be patterned, and (2) the overlay, OV, which is the alignment accuracy of two patterns on top of each other [11-13]. Both parameters are schematically shown in Fig. 1c. Nowadays, the most advanced chips are manufactured in the so-called '3 nm node' with a pitch of 24 nm for the tightest metal lines [6]. Each chip manufacturer develops and improves its fabrication processes to optimize the chip production yield as well as chip performance – and to stay ahead of its competitors.

MICROPATTERNING BY UV-LITHOGRAPHY IN OUR MICROFAB

At our institute THUAS in Delft, we have a microfabrication laboratory, MICROFAB, where we can execute complete lithography cycles to produce micropatterns on small-size wafers (Fig. 2-4). Our facility is equipped with two lithography systems based on UV-lithography with wavelengths close to 400 nm, which enable the imaging of patterns with critical dimensions of about a micron (if the fabrication processes are fully optimized). One of our lithography machines is a Karl Suss MJB-3, which is a contact-mode mask aligner. The other lithography machine is a DMO ML-2 laser direct-write lithography machine (Fig. 2d). Currently, we are only using the laser writer in our microfabrication processes because it is a maskless lithography machine with much flexibility in designing and imaging micropatterns.

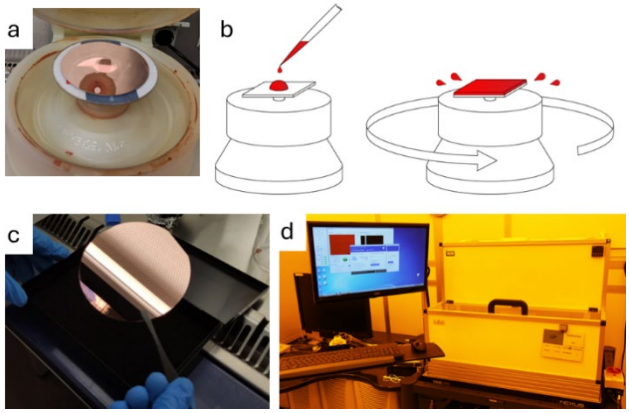

Fig.2. (a) Wafer on spincoater. (b) Principle of spincoating photoresist. (c) 4" silicon wafer. (d) DMO ML-2 laser writer for maskless UV-lithography. Pictures adapted from [14-16].

Fig. 3 shows a schematic overview of a typical lithography cycle that students execute in the MICROFAB. The lithography cycle starts with the design of a microstructure in the design software 'KLayout'. Then, a small-sized silicon sample is diced from a 4" wafer (Fig. 2c) and precleaned. Afterwards, a uniform photoresist layer of 1.2 µm is spin coated on top of the sample (Fig. 2a-b). Subsequently, the coated sample is loaded in the laser writer (Fig. 2d) and the pattern design is transferred from 'KLayout' to the control software of the lithography machine. After sample positioning and alignment procedure, the lithography step (i.e., the laser writing process) is executed to generate an image of the design in the photoresist.

When the laser hits the polymer-based photoresist layer on top of a sample, its chemical composition changes (i.e., a laser-induced decomposition process occurs), as schematically shown in Fig. 4. The laser can be set at a wavelength of 375 nm (with a beam size of 1.0 µm) or 405 nm (with a beam size of 0.6, 1.0 or 5.0 µm). The beam settings are carefully chosen for each lithography cycle. The energy dose (from the laser to the resist) depends on the exposure time of the laser on the resist. A dose test needs to be executed prior to each new lithography

process to optimize the dose. When the lithography step has finished, the sample is dipped in a developer that only dissolves the laser-exposed resist (Fig. 4). The obtained micropattern in the resist needs to be inspected to assess the image quality (as compared to the design).

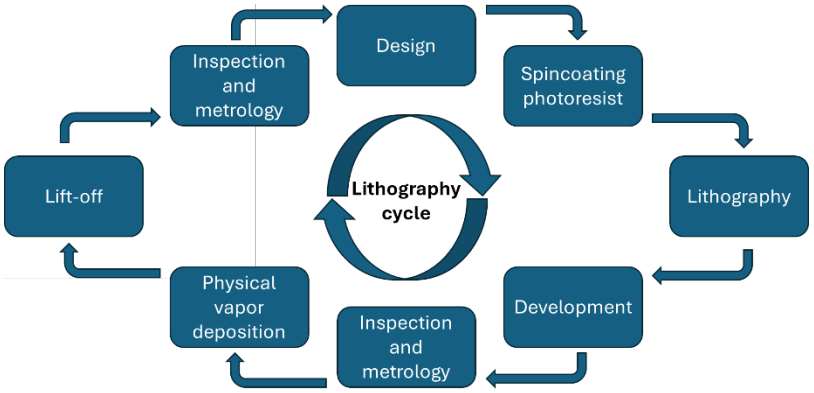

Fig.3. Lithography cycle for a lift-off microfabrication process.

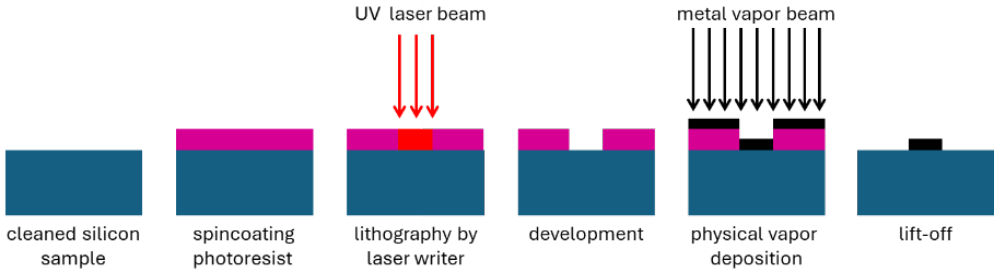

Fig.4. Cross-sections of a wafer at subsequent processing steps of a lift-off process.

After successful imaging, the developed sample is transferred to a physical vapor deposition (PVD) system to create a metal layer on the sample (Fig. 4). For example, aluminum and/or copper layers can be deposited with a typical thickness in the range of 10 to 100 nm. When the PVD process step is finished, the sample is transferred to a resist stripper. A micropatterned metal layer is left on top of the sample after this so-called lift-off process (Fig. 4). The pattern needs to be characterized by metrology tools, such as optical microscope (OM), scanning electron microscope (SEM), profilometer and/or atomic force microscope (AFM) to compare the patterning result with the design.

In general, lithography processes are improved by executing a control parameter study (e.g., varying resist thickness, dose, development time, etc.). Process optimization is done by analyzing the statistical variation of key-performance indicators (KPIs), such as critical dimensions and overlay. The metrology results are used as feed-forward to adjust the design and/or to fine-tune process parameters of the lithography cycle in a holistic way (Fig. 3).

LITHOGRAPHY CHALLENGES FOR PHYSICS AND ENGINEERING STUDENTS

In this section, I will present recent project results to illustrate the type of lithography projects that 3rd and 4th year's bachelor students execute in our MICROFAB facility. The first

project team focused on the patterning performance of the lithography machine for structures with critical dimensions (CD) ranging from 100 µm down to 1 µm. The second project team aimed for characterization of the alignment performance of the lithography machine for structures at the 10 µm technology node.

The first project group used dose and development time as control parameters to develop a fabrication process for microstructures with CD approaching 1 µm. Fig. 5a shows the design of several series of lines with varying widths, from 1 µm (top row) to 100 µm (bottom row). Each column of the design is written by the laser writer with a different dose, ranging from 80 mJ/cm^2 to 110 mJ/cm^2. The same design is written on different samples for which different development times were used between 45 and 65 seconds. The students improved iteratively the fabrication process, and finally were able to write lines with widths of ~1 µm. Fig. 5b shows the patterned lines after physical vapor deposition of Al (40 nm) and Cu (80 nm) and lift-off. Although the students proved the fabrication of patterns with CD ≈ 1 µm, the line patterns exhibit a relatively large line width roughness (LWR) and line edge roughness (LER). The students wrote Python scripts to quantify LWR and LER for each line, because LWR and LER are important KPIs for the lithography process. Fig. 6 illustrates the automated LWR/LER data analysis based on SEM images of fabricated micropatterns. Their results represent an important step forward on our lithography & patterning roadmap.

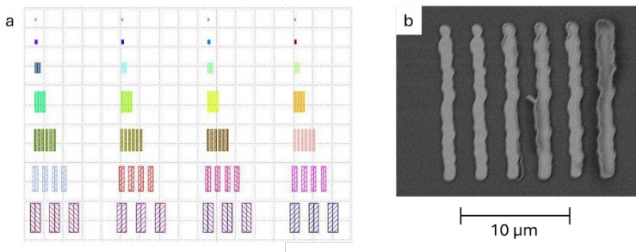

Fig.5. (a) Design of dose test patterns with different CD. (b) SEM-image of Al/Cu lines with CD ≈ 1 µm. Pictures adapted from [15].

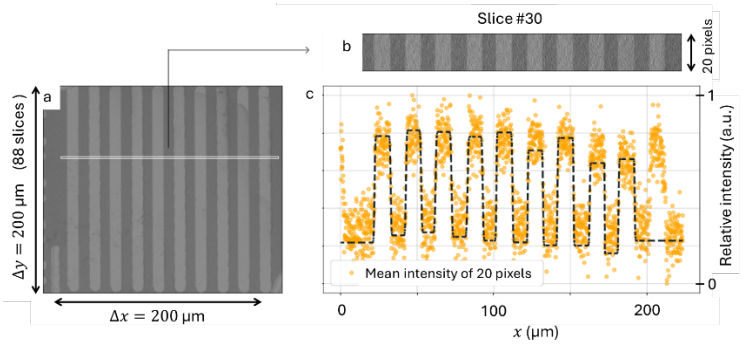

Fig.6. (a) SEM-image of Al/Cu lines. (b) Slice from SEM-image for data extraction. (c) Metrology on extracted data to determine CD errors. Pictures adapted from [16].

The second project group used the alignment marks as control parameters (i.e., mark shape, mark size, and mark-to-pattern distance) to develop a fabrication process for accurate alignment of two structures at the 10 µm technology node. Fig. 7a shows the design of two patterns that need to be aligned to each other. First, the black pattern is fabricated in a lithography cycle (including physical vapor deposition of an Al/Cu layer and lift-off). Then, after an alignment procedure, the green pattern is fabricated in a second lithography cycle. Fig. 7a shows different

sets of alignment marks (i.e., diamonds/circles) that are used for the alignment procedure. The overlay (OV) of both fabricated patterns is assessed by using SEM-images (Fig. 7b). The OV is determined by a set of KPIs: magnification error, translation error (x and y) and rotation error. The students wrote Python code to obtain these OV errors automatically from the SEM images. Fig. 7b clearly shows that the left side of the pattern has smaller OV errors than the right side of the pattern. Although the origin of these OV errors is not fully understood yet, it seems that these are systematic errors. Currently, students try to determine an accurate error correction procedure to improve the alignment performance of the lithography machine.

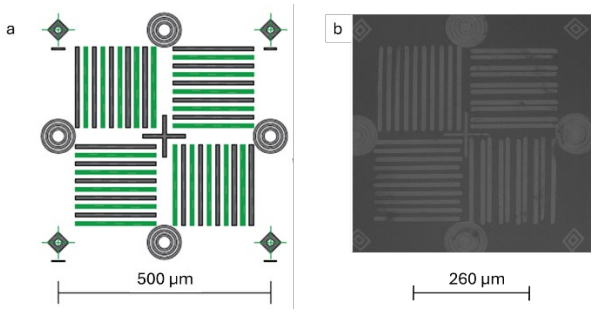

Fig.7. (a) Design of pattern 2 (green) that needs to be aligned with pattern 1 (black). Note that the diamonds and circles are the alignment marks. (b) SEM-image of the fabricated patterns that are used for assessment of OV errors. Pictures adapted from [16].

A future milestone will be the successful realization of microstructures by multi-cycle lithography processes, and the characterization of the electrical performance of such microsystems. This microtechnology direction will pave the way to develop application-specific (electronic) microdevices and sensors. Therefore, our technology roadmap will be co-optimized with application-driven roadmaps at the lectorates in our engineering department.

PROFESSIONAL COMPETENCE GROWTH

Technologically challenging projects in our MICROFAB are crucial for letting students grow towards competent lithographers/microtechnologists who can autonomously coordinate and execute research, development, engineering and/or prototyping cycles by taking end-to-end ownership of projects. Students need to show a collaborative attitude within their project, but also constructive communication with other project teams during cross-functional progress meetings.

Working in a professional microfabrication laboratory requires a safe and clean working culture which is respected by all users of the facility. Students will learn by doing that the success of a project highly depends on a goal-oriented, systematic, and accurate way of working. Therefore, students are only allowed to enter the lab if they have a detailed work plan and a lab-book to make notes when executing the work. The nature of lithography projects forces students to troubleshoot process defectivity and execute root-cause analyses if needed. Moreover, students experience that it is beneficial to have a creative, pragmatic, and persistent mindset to investigate recurring technical issues, to generate robust solutions, and to mitigate processing risks. Often feasibility studies of new process steps need to be done prior to the integration in a microfabrication procedure. Students will learn to perform accurate metrological analyses that are crucial for design choices and process optimization.

When a student grows as a competent and skilled lithographer during the trainings, he/she will become more capable of overseeing lithography projects and will be able to identify major

improvements and novel innovations in microfabrication processes in general. Graduated students will be equipped with a valuable set of competences and skills that are an asset for having a career in the semiconductor industry and related ecosystems.

DISCUSSION

There is a strong need for well-equipped microtechnology facilities at universities of applied sciences in The Netherlands. For universities of applied sciences in general, it is very difficult to build-up their own microtechnology facilities, and moreover, to cover the operational and maintenance costs which are usually very high. However, such facilities are crucial for training students microtechnology and lithography skills within the study program. Microtechnology facilities will enable the in-house execution of real-life projects in collaboration with external partners in the high-tech ecosystem. The students' competence growth will accelerate if students can work already in an early stage of the study program on technology-oriented and application-driven projects. Europe will benefit strongly if universities of applied sciences have their own microtechnology facilities that are embedded in the network of competence centres that Europe is planning to establish, according to the 'European Chips Act' [4].

Although the 'Chips for Europe Initiative' only started in 2022 [4], the EU had already two related international programs running since last decade: (1) EU's Graphene Flagship since 2013 on the application of graphene and related two-dimensional materials, such as electronic, opto-electronic, and electromechanical microdevices [17], (2) EU's Quantum Flagship since 2018 on quantum computing, quantum communication and quantum sensing technologies [18]. Interestingly, competence centres are established within these EU programs. For instance, a so-called Talent & Learning Centre (TLC) is founded in the Netherlands in 2023 for creating strong ties between educational organizations (i.e., vocational schools, universities of applied sciences and academic universities) and the rapidly expanding Dutch quantum ecosystem [19]. Similar TLCs are planned for the growing Dutch photonics ecosystem with a focus on photonic integrated circuits [20]. Integrating these interrelated competence centres in a large EU network will be a great asset for the 'Chips for Europe Initiative'. A network of competence centres will fuel the workforce that Europe's semiconductor ecosystem needs for its intended growth.

CONCLUSIONS

Universities of applied sciences can play a key-role to reinforce Europe's position in the global semiconductor industry. The foundation of competence centres and technical facilities at educational institutes is crucial to educate young, competent, skillful professionals for Europe's expanding semiconductor industry.

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FLIPPED CLASSROOM IN TEACHER EDUCATION

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The lecture Basic Principles in Physics is a compulsory subject in the education of primary school teachers at TU Dortmund University and actively attended by 100 to 150 students. Previously the lecture was held as a classic lecture utilizing mainly power point slides and experimental demonstrations. For the winter term 23/24 the lecture format was shifted towards a more interactive format, aiming at specific physics problems to be solved as part of the lecture. In order to free up the necessary time in the lecture itself , the conveyance of knowledge was shifted to the students' preparation for the individual lectures, by providing texts and videos, which were aided by a short quiz. The lectures as well as the preparation were accessed over the entire semester. This paper provides an overview over the results obtained from the assessments and the final exams, as well as the lessons learned.

Keywords: Flipped Classroom, Just-in-Time-Teaching, Teacher Education

INTRODUCTION

The lecture Basic Principles in Physics is a compulsory subject in the education of primary school teachers at TU Dortmund University [1] and is actively attended by 100 to 150 students in their third semester. Providing students with fundamental knowledge on physics, which can be applied in their own teaching throughout the course of their professional career, is one of the main goals of the lecture. Within the curriculum, the lecture is embedded in the general science education of the students, which also contains lectures with similar aims in Biology, Chemistry and Engineering [2]. The lecture is taught as a weekly 90 minute lecture over the course of one semester. In order to proceed with their education students are required to pass a combined exam on Physics and Engineering at the end of the semester. Although the exam covers two subjects, topics from both subjects are clearly separated. Students pass the exam in case they obtain at least 50% of the total points, regardless of the subject the points were obtained in.

The lecture covers a broad range in classical physics, including Newtonian mechanics, thermodynamics, electricity and magnetism as well as some aspects of astronomy, for example the solar system.

Over the last years, the lecture was taught in the form of a classical lecture, utilizing mainly power point slides, experimental demonstrations and blackboard calculations. Within this lecture format the engagement of the students was relatively low, which was reflected in the lecture assessments and the relatively poor performances in the final exam. For the winter term 23/24 the lecture format was re-designed to allow for more student participation and the focus on specific physics problems to be solved as part of the lecture. Flipped classroom (cf. [3,4]) and just in time teaching elements [5] played a major role in the re-design. In order to assess the students perception and engagement the lecture was closely monitored via regular assessments throughout the entire semester. Due to the overall structure of the lecture, it was found to be very difficult to assign extra credit to students for participating in the assessments. It would, however, been beneficial to do so in order to increase the overall participation rate.

This paper will provide an overview over the results of the assessments and some selected learning outcomes, reflected by the final exam, and is organized as follows: The next section will first provide an overview over the interest and existing knowledge of the student group and briefly explain the key elements of the re-designed lecture format. After that, the outcomes of the assessments as well as an analysis of selected topics from the final exam will be presented. The final section will conclude the paper with lessons learned and provide an outlook on possible further improvements for the lecture.

CHARACTERIZATION OF THE STUDENT GROUP AND RE-DESIGN OF THE LECTURE FORMAT

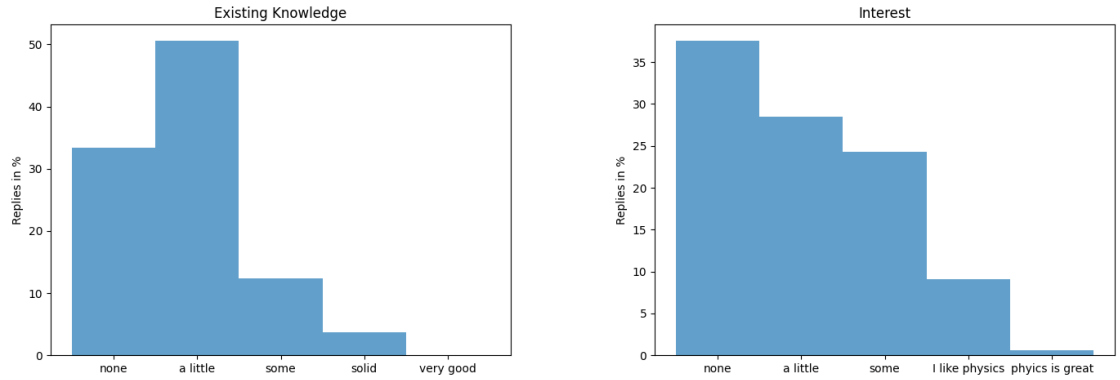

Fig. 1. Existing knowledge (left) and general interest in physics (right).

As a central part of the first lecture the students were asked to participate in an assessment aiming at analyzing their existing knowledge, as well as their general interest in physics. This particular assessment was carried out in class via an audience response tool (mentimeter) The outcome of the assessment with respect to the existing knowledge in physics is shown in Fig.1 (left), whereas the outcome with respect to the students' interest is shown on the right hand side of Fig.1.

One finds that majority of the students claims that they have either none or only a little physics knowledge. Only 12% of the students indicated that they have some knowledge in physics and (expectedly) even less (4%) claim that they possess a solid physics knowledge. None of the students responded that they had a very good knowledge in physics.

The situation is similar for the students' general interest in physics, where the vast majority of the students claims that they have either no (38%) or only a little (29%) interest. Almost a quarter (24%) of the students responded that they had some interest in physics, whereas less than 10% stated that they liked physics. A single of the 165 participating students responded that physics was great.

In addition to the two items discussed above, the students were also asked for how many years they had learned physics in school, if they participating in the lecture for the first time and if they had any experience with the flipped classroom method.

Taking into account the outcome of these assessments, one can conclude that the majority of the learning group has neither a strong interest, nor a solid knowledge in physics. This indicates that a strong activation of the students should be built up during the lecture in order to keep the students engaged, which was also expected to result in an improved learning outcome. In addition to providing specific physics problems (preferably from the everyday

experience of primary school children) an increased engagement of the students, was one of the primary goals of the re-design of the lecture, which will be described in the following.

For the winter term 23/24 the lecture format was re-designed using central elements from the flipped classroom method and just in time teaching. The overall structure of the lecture consisted of three central parts: the students' preparation for the lecture, the lecture itself and additional exercises provided to the students on central topics.

The preparation of the students was organized via the online learning environment moodle [6] and presented in individual units. Each unit started with a brief general introduction on the topic, listing the main points to be prepared by the students. Although it was generally left open, which materials the students should utilize during the preparation phase, texts and videos on the individual topics were provided. From the student side, the preparation was concluded by participating in a short quiz, covering selected matters from the texts and videos.

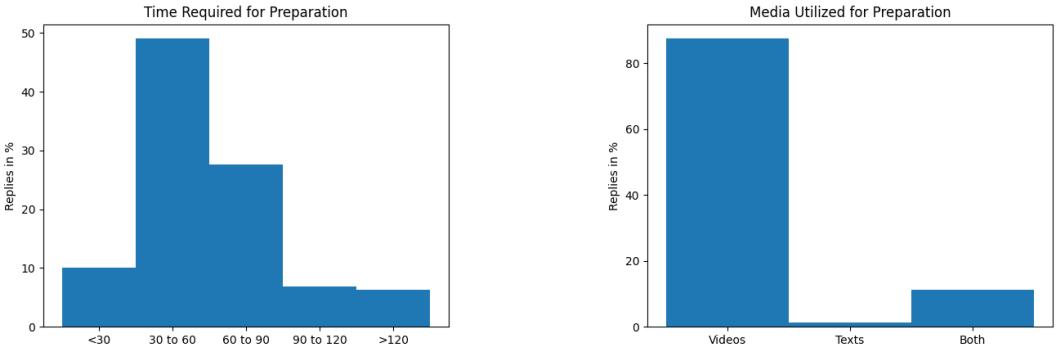

Fig.2. Time Demand (left) for Preparation and Utilized Media (right).

Before the lecture, the students were offered to participate in a short assessment offered via moodle, where they could indicate how much time they had spent on the preparation material in total and which of the provided materials they actually utilized in their learning. Furthermore, the students were given the opportunity to write down certain topics they had not or not completely understood during the preparation.

Both, timing and not fully understood topics, were considered critical point for the overall success of the new lecture format. In case students are overwhelmed by too much learning material to be covered before the actual lecture, they might become disengaged and ultimately refuse to prepare for the lecture. In order to prevent this, the goal was that on average students would spend 30 to 60 minutes per week on the preparation for the lecture.

With respect to not fully or not all understood topics, these topics were extracted from the assessment and separately addressed during the lecture. Unfortunately it is in many cases infeasible to address all of the mentioned topics. However, picking the three to four most frequently mentioned ones, was expected to improve the overall learning outcome of the students.

Fig.2. depicts the time demand (left), as well as the media utilized for lecture preparation by the students. One finds that the average goal of having the students spend 30 to 60 minutes on the preparation was met to a large extent. It should, however, be noted that the figure depicts the students answers aggregated over the entire term. Due to the different complexity of the individual topics, the time required for preparation slightly varied from topic to topic. The

continuous monitoring of the students' efforts, however, allowed for longer preparation assignments to be followed by shorter ones, to even out the time demand over the course of the semester.

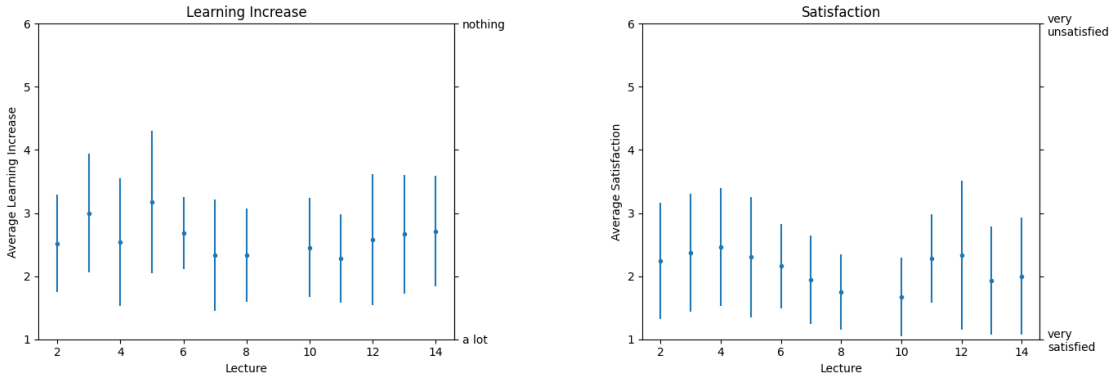

Fig.3. Average learning increase (left) and average satisfaction (right).

With respect to the utilized media it is not surprising that the vast majority of the students (88%) solely relied on the videos for preparation. Approximately 11% utilized texts and videos to prepare for the lectures, whereas less than 2% of the students used the texts.

Within the lecture the students were confronted with specific physics problems, that could be solved using knowledge acquired in the preparation phase. For low complexity problems of the students were either asked to answer via an audience response tool. In order to solve more complex problems possible solution strategies were discussed in class and the problem was then solved on the blackboard in a collaborative effort.

RESULTS OF THE LECTURE ASSESSMENT

Assessing the students perception of the lecture over the entire course of the semester (also via moodle), allowed for a continuous monitoring of the latter. The outcome of said assessment with respect to the students' satisfaction with the lecture format and their perceived learning increase is shown in Fig.3. While the students' perceived learning increase is shown on the left hand side of the figure, the students' satisfaction is depicted on the right hand side. For both subfigures, one finds that the first, the last and the ninth lecture were not evaluated. For the first lecture, this is due to the fact that this lecture was utilized to explain the motivation behind the chosen lecture format to the students and to clearly communicate the expectations with respect to preparation. The last lecture, was labelled irrelevant with respect to the exam on short notice, due to a strike of the German train personnel, which hindered a large amount of students from personally attending the lecture. Lecture number nine was held by a substitute in a classic lecture style and was therefore also not evaluated with respect to the students' perception on the changed lecture format.

For the assessment of the perceived learning increase, the students were provided with a scale from one to six, with one indicating that the students learned a lot, and six indicating that the students did not learn anything. To obtain the average learning increase for the entire learning group, the students' replies were averaged and the depicted error bars indicate one standard deviation. One finds that for all lectures the average perceived learning increase is between two and three, indicating that the participating students were able to increase their knowledge by a substantial amount, by participating in the lecture.

For the assessment of the students' satisfaction, the learners were again provided with a scale from one to six. This time one indicates that the participants were very satisfied with the lecture format, whereas six indicates that the learners were not satisfied at all. The participants' satisfaction was again analyzed by averaging the students' answers. As above, the depicted error bars correspond to the one sigma environment. The students' average satisfaction with the lecture format is found to be in the range between two and three for all lectures, indicating that the learners were relatively satisfied with new format. However, the error bars indicate that some students were more satisfied with the lecture format than others.

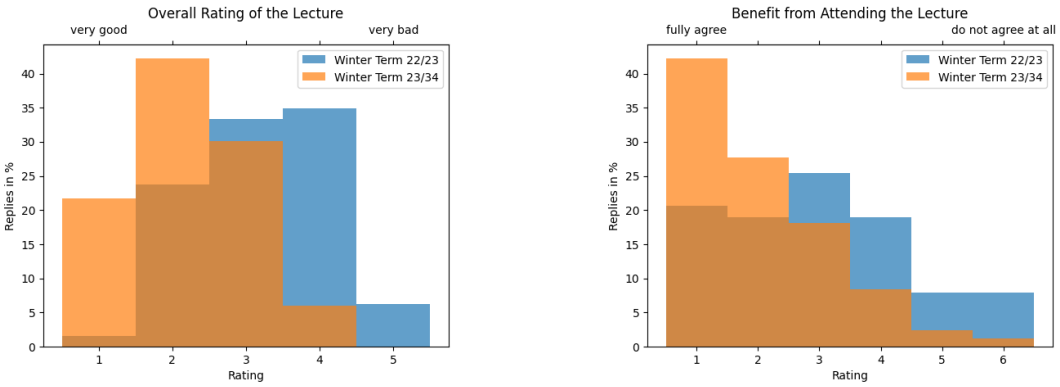

Fig. 4. Overall rating of the lecture (left) and perceived benefit from attending the lecture (right).

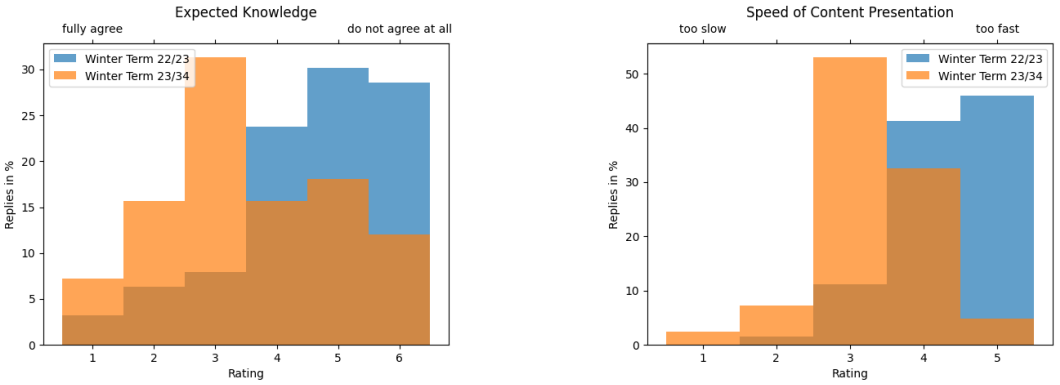

Fig. 5. Expected knowledge (left) and speed of the presentation (right).

RESULTS OF THE FORMAL LECTURE EVALUATION

The lecture was also formally evaluated via a different online survey tool by the physics department via a standardized set of questions. This formal evaluation is carried out on all classes exceeding a certain number of participants after approximately 50% of the lectures have been held. The evaluation is quite detailed and this paper will only present four key findings with respect to new lecture format.

Figure 4 shows the overall rating of the lecture (left), as well as the students' perceived benefit in attending the lecture compared to studying the material by themselves. The results for winter term 23/24 (orange) are compared to the results for winter term 22/23 (blue), where the lecture was held as a classical lecture.

With respect to the overall rating of the lecture one observes an increase towards a better rating. In WT 23/24 approximately 64% of the students rated the lecture as good or very good, compared to 25% in WT 22/23. For WT 23/24 none of the participating students rated the

lecture as very bad, compared to 6% for WT 22/23. Considering the perceived benefit from attending the lecture in WT 23/24, 70% of the students agree or fully agree that they benefit from attending the lecture, compared to 40% in WT 22/23. In WT 23/24 only a very small portion of the students (4%) do not (or only marginally) agree that they benefit from attending the lecture, compared to 15% in WT 22/23.

The left hand side of Fig. 5, depicts the answers to the question, whether the students did possess the knowledge expected for actively following the content of the lecture. Results for WT 23/24 are shown in orange, whereas the results for WT 22/23 are depicted in blue. Although, a large number of students (46%) is under the impression that they do not possess the expected knowledge, one observes a shift to the left. This shift indicates that for WT 23/24 more students had the impression to possess the required knowledge. This becomes even more interesting, when considering that the knowledge required for the lecture remained unchanged with respect to WT 23/24. One can therefore conclude that the students' perception of their already existing knowledge was positively influenced by the learning material provided for preparation.

The right hand side of Fig. 5. shows the speed of the content presentation as perceived by the students. Results from WT 22/23 are shown in blue, whereas results from WT 23/24 are depicted in orange. A numerical rating scheme ranging from one to five was used, with one indicating that the content was presented too slow and five indicating that the content was presented too fast. For WT 23/34 the graphic clearly shows that the majority of the students (53%) responded with three, which implies that the speed of the presentations was just about right. This can be considered a big improvement to the overall quality of the lecture, compared to WT 22/23 where 87% of the students perceived the speed as either too fast or slightly too fast.

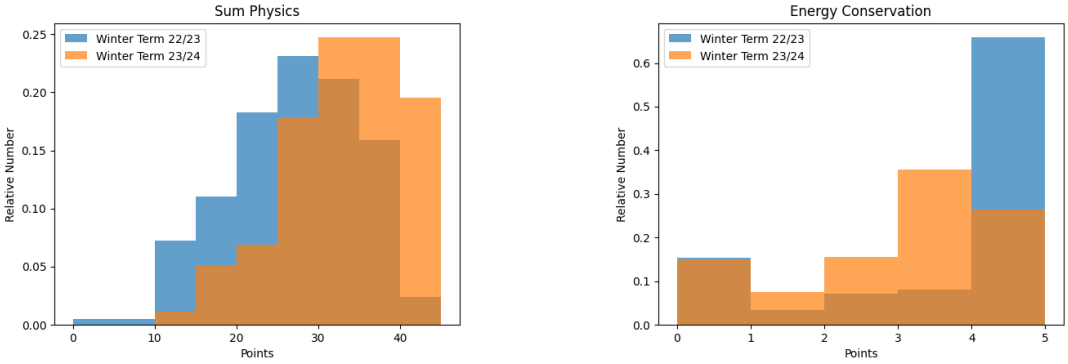

Fig. 6. Number of points obtained by the students in the final exam (left) and number of points obtained by the students in a question on energy conservation (right).

RESULTS OF THE LEARNING OUTCOME

The students learning outcome was assessed via the results of the final exam. Within those final exams questions were exemplarily selected based on the underlying skills, required for solution. These questions were then compared to questions from the previous exam, which tested for similar skills. As part of this paper, the results with respect to the concepts of energy- and momentum conservation, as well as in one question aiming at the simple reproduction of knowledge (e.g. asking for different kinds of temperature scales or different conservation laws),

will be presented. Furthermore, the overall number of points obtained by the students will be compared to the previous exam.

Due to the curriculum taught at TU Dortmund University, the exam is a single exam taken simultaneously on physics and engineering. The duration of the exam is 90 minutes, with a total number of points of 90. Students pass the exam in case they receive at least 50% of the total points independent of the subject they received them in. It is only possible to pass or fail the exam as a whole. For this paper, the results of the exam are only evaluated with respect to the physics questions.

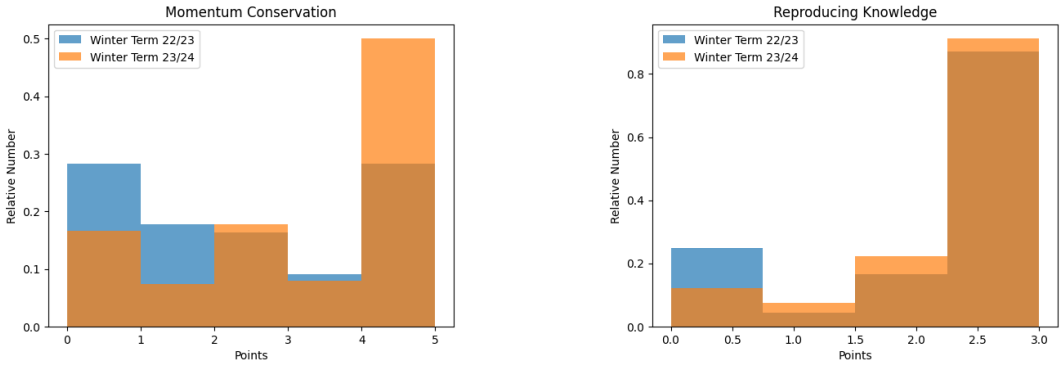

Fig. 7. Number of points obtained by the students in a question on momentum conservation (left) and in a question requiring the simple reproduction of knowledge (right).

Figure 6 shows the total number of points obtained by the students in the final exam (left), as well as the number of point obtained in a question on energy conservation (right). Results obtained for WT 22/23 are shown in blue and results obtained for WT 23/24 are depicted in orange. With respect to the total number of points one recognizes a prominent shift towards a larger number of points, when comparing WT 23/24 and WT 22/23. Comparing WT 22/23 and WT 23/24 with respect to students ability to apply the concept of energy conservation, one finds that in 23/24 a smaller number of students received the maximum number of points on this question.

Figure 7 shows the number of points obtained in a question on momentum conservation (left) and in a question that required the simple reproduction of knowledge (right). With respect to momentum conservation one finds that in 23/24 (orange) approximately 50% of the participants obtained the maximum number of points on this question. This is an increase compared to 22/23, where approximately 30% of the students obtained the maximum number of points. One further observes an overall shift in the distribution towards a larger number of points, when comparing 22/23 and 23/24. With respect to the reproduction of knowledge one also observes a shift towards a larger number of points, when comparing WT 23/24 and WT 22/23. Although in this case, the shift is less prominent one finds that a smaller number of participants (approximately 12%) obtained no points on this question in 23/24 compared to approximately 25% in 22/23.

SUMMARY AND OUTLOOK

For the winter term 23/24 a lecture that was previously taught in a classical docent-centered setting was changed towards a more student-centered approach, which adopted elements from just-in-time-teaching and the flipped classroom method. In addition to the mandatory evaluation of the lecture and the results of the final exam, which provided insights into a change

in performance, the students' perception of the lecture format was continuously monitored over the course of the semester.

The analysis of the regular assessments revealed that the students were generally satisfied with the chosen lecture format and that they perceived a relatively high increase in learning when actively attending the lecture.

With respect to the formal lecture evaluation it was found that the overall rating of the lecture was improved and that the students perceived attending the lecture as more beneficial. Furthermore, the overall speed of the lecture was rated as just about right, which is a direct consequence of providing students with preparatory material. Having the students work through said material before class, frees up additional time within the lecture, which can e.g. be put to use by providing additional examples or by covering certain aspects in greater depths.

Considering the results of the final exam, it was found that the students performance greatly increased compared to winter term 22/23, as a prominent shift in the distribution towards a larger number of points is observed. Although a slight decrease in the total number of points is observed for a question on the conservation of energy, the students' performance on a momentum conservation task was found to greatly improve. For a question that only required the simple reproduction of knowledge, this enhancement in the students' performance is also apparent but less prominent.

In summary, changing the lecture format from a traditional format to flipped classroom teaching can be considered very successful. The improvements not only manifest themselves in the students' performance in the final exams, but also in their more positive attitude towards the lecture in general. The very promising results and the very positive feedback by the students are very motivating with respect to a permanent change in the lecture format.

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THE QUANTUM MECHANICS VENUE – A TRANSFORMATION TO A CROSS REALITY LEARNING-TEACHING LAB

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The Quantum Mechanics Venue is a learning teaching laboratory for high school students at TU Dortmund University. In this context the lab is continuously used and developed by university students. The lab itself focusses on conducting key experiments in quantum mechanics and the visualization of quantum mechanical effects. By exploiting the contradiction between classical expectation and experimental observation, cognitive dissonances are stimulated and later resolved, which leads to an increased learning outcome. Conducting existing experiments is, however, in some cases hindered by a complicated alignment, which does not aid the quantum mechanical understanding. The desired learning outcome can thus not be achieved in all cases.

In order to address these challenges and to allow for a future remote use of the laboratory, three pilot experiments were transformed into cross reality labs. This allows to decouple the students' learning experience from the location of the lab. This paper provides an overview over the digitized experiments and gives an outlook on the future of the learning teaching laboratory.

Keywords: Cross Reality Laboratories, Quantum Mechanics, Ultra-Concurrent Labs

INTRODUCTION

The Quantum Mechanics Venue [1] is a learning-teaching lab for high school students at TU Dortmund University, which is actively used and developed by university students, e.g. via Bachelor's and Master's theses. Within the lab, key experiments from quantum mechanics can be conducted and the pedagogic focus is put on stimulating cognitive dissonances, which arise from the contradiction between classical expectation and experimental observation [1]. These dissonances are then resolved through the use of quantum mechanics, e.g. via the wave-particle-duality. The Quantum Mechanics Venue is further linked to teacher education in physics, via its integration into different seminars. High school students generally visit the lab in groups.

Although the main focus of the lab is on a deeper understanding of quantum mechanics, certain experiments require a more complicated alignment and in some cases, the quantum mechanical effect is difficult to observe. Despite the fact that the adjustment of material and the first-hand observation of experimental effects are highly valuable skills that should be developed within high school students, neither the alignment nor barely observable effects aid the primary learning goals of the lab. Furthermore, the COVID-19 pandemic has enhanced the need for a laboratory in which the learning experience can be largely decoupled from the physical location of the lab.

As a consequence, three pilot experiments were exemplarily digitized. The teltron tube [2], designed for measuring the specific charge of the electron, as well as the Millikan experiment [3] were re-designed as simulations, whereas the Franck-Hertz experiment [4] was converted into a ultra-concurrent laboratory [5]. This paper provides an overview over the preliminary

results of the ongoing digitization project, highlights the lessons learned and tries to provide an outlook on the future of the Quantum Mechanics Venue. The paper is organized as follows:

The next section provides an introduction into the challenges of learning-teaching laboratories in the digital age. After that, the simulated experiments as well as their current status are reviewed, before a prototypical ultra-concurrent lab on the Franck-Hertz experiment is introduced. The paper concludes with a summary and an outlook

LEARNING-TEACHING LABORATORIES IN THE DIGITAL AGE

The term cross-reality labs summarizes all laboratories that are either fully digital or digitally enhanced. More specifically, this includes virtual reality (VR) labs, as well as augmented reality (AR) labs, where the user can be provided with additional information, e.g. on the experiment itself or on certain parameters and settings. Mixed and merged reality (MR) labs are also included in this description [5,6]. While VR-labs are fully simulation-based, which offers a wide range of possibilities with respect to their development and application, AR is generally applied in actual labs, but with virtual assistance, for example via the real-time display of sensor data on a smartphone or tablet [7].

Remote laboratories, are generally not entered by the students and can be subdivided into ultra-concurrent labs and actual remote laboratories. In both cases experiments as well as their outcome are accessed online. Ultra-concurrent labs make use of video sequences which depict the outcome of an experiment for a certain combination of parameter settings [5]. Capturing individual videos for each entry in a parameter matrix, can be relatively time consuming, as the size of the parameter matrix and hence the number of required videos, grows with the power of the number parameters. Furthermore, the videos might require a certain amount of editing before being released to the public. However, once the video sequences have been produced, they are in principal available to an infinite number of students at the same time. Remote laboratories, are in general limited to one group of students at a time, as the experiment is carried out by a teaching assistant, which interacts with the group of students via a video-conferencing tool.

Although the implementation of the different remote laboratories varies, they have in common that they are largely independent of the whereabouts of their users, which facilitates self-organized learning on the student side. They further eliminate the possibility of accidents, when working with potentially dangerous lab equipment, for example high voltage, and allow for a better reproducibility of the experimental results. In addition remote laboratories are desirable from an economic perspective, as expensive lab equipment can be shared between different facilities, which can also be considered as a step towards more sustainability in university education.

In spite of the positive aspects of cross reality labs, they should not be implemented for their own sake. As with every learning task, the utilized technology should align with the desired learning outcome, not the other way around. Moreover, cross reality labs should not be implemented in order to replace labs in reality. Aligning and calibrating laboratory equipment, as well as reading measurement values from different meters are highly important skills, which are difficult to teach via remote access. Utilizing cross reality labs therefore makes sense in cases where the anticipated learning outcomes can be reached for efficiently.

SIMULATIONS: MILLIKAN-EXPERIMENT AND TELTRON TUBE

Within the digitization efforts the Millikan experiment and the teltron tube were chosen as initial cases for implementation as 3D simulations via UnrealEngine5 [8]. In both cases the underlying physics can be simplified for visualization, as it does for example not require

complex numerical simulations. In addition, the required visualizations appear comparatively straightforward in both cases.

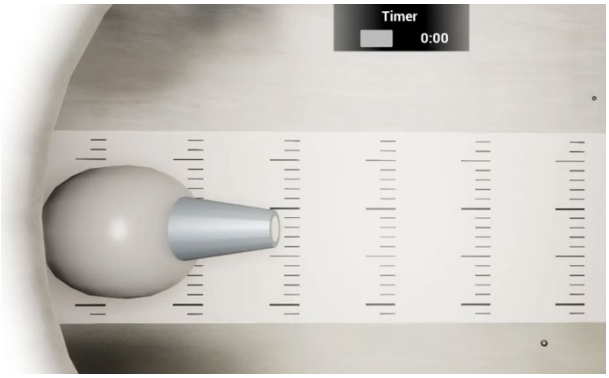

Fig. 1. Screenshot showing the basic setup for the digitized version of the Millikan experiment. The nebulizer on the left hand side can be used to spawn oil drops, which can then be viewed on their trajectory inside the electric field.

The Millikan experiment measures quantization of the elementary charge via oil droplets, which move up or down in an electric field, depending on the polarization of the field. Using the velocity of the droplets, as well as assumptions about the radii of the droplets then allows for the extraction of the charge of the droplets. A minimal simulation of the Millikan experiment thus only requires the simulation of droplets, moving up or down in front of a scale, due to the applied electric field. This can be achieved by only a handful of parameters: the charge of the droplet, the voltage applied in order to generate the electric field and the size of the droplet, where the latter could in principle be ignored in an extremely minimal version of the simulation.

In a teltron tube, electrons generated in a thermionic cathode are accelerated in an electric field, before being injected into a neon-filled glass flask. The flask itself is embedded in a set of Helmholtz coils providing a magnetic field, perpendicular to the velocity of the electrons. A Lorentz force then acts on the electrons forcing them onto a circular trajectory. The centripetal force acting on each electron as a consequence of its circular trajectory is then equal to the Lorentz force, which can be used to extract the specific charge (e/m) of the electron. As in the Millikan experiment, the visualization of the most important physics effects can be achieved with relatively small effort. The main parameters to be accessed by the user are the radius of the circle, the magnetic field of the Helmholtz coils (accessible via the current through the coils) and the voltage used for the acceleration of the electrons. From the visualization side, only a circle and a scale to measure its radius are required.

Although the minimal implementations of both experiments do not necessarily require complex graphics engines, their utilization offers a couple of benefits. One of these benefits is that starting from a simple scratch-like implementation, enhancements can easily be made and that using Unreal Engine [8] or Unity [9] allow for appealing graphics, which help keeping the students engaged. Compared to simple one-dimensional simulations, which would in principle be sufficient to achieve the anticipated learning goals, 3D simulations allow for the user to select different perspectives in order to fully comprehend the underlying physics.

Compared to conducting the hands-on experiment, simulations for example allow for the permanent visualization of the physics parameters, e.g. the radius of the circle or the charge of an oil droplet. Said visualizations can be turned on and off by the user in case they are needed

to aid the understanding of the experiment. This enables students with different skill levels to directly access the amount of help required for them to successfully complete the measurement.

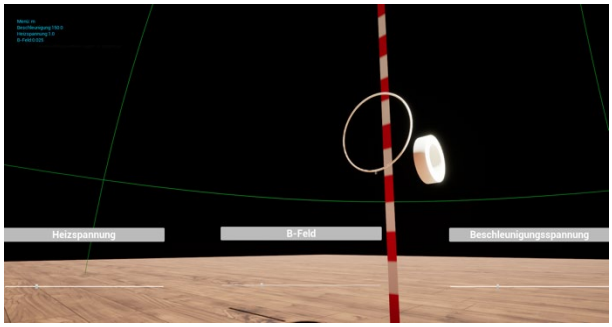

Fig. 2. Screenshot taken from the prototype simulation of the teltron tube. The finer of the two rings corresponds to the electron beam held on a circular trajectory. The red and white scale in the back can be used to determine the radius of the ring.

ULTRA-CONCURRENT LABS: FRANCK-HERTZ EXPERIMENT

The Franck-Hertz experiment is utilized for the determination of the specific excitation energy of either Ne- or Hg-atoms. Energy is transferred to the atom via inelastic scattering with electrons, which are accelerated in an electric field with a voltage U. Said voltage is continuously increased from zero to100 V. In case the electrons do not lose all of their kinetic energy in scattering they are collected by a cathode, where a cathode current can be measured, accordingly. The excitation of the atoms becomes visible inside the Franck-Hertz tube through a ring of light. At higher voltages the electrons carry sufficient energy to undergo multiple scatterings and multiple excitation zones can be observed, accordingly. At the right settings, the cathode current follows a distinct shape, which is generally monitored by an oscilloscope. The maxima of the cathode current are then utilized to determine the excitation energy of the atoms.

Within the digitization efforts of the Quantum Mechanics Venue, a prototype of an ultra-concurrent lab for the Franck-Hertz experiment was realized as a thesis project [10]. The equipment of this experiment does not require a particular alignment, except for the oscilloscope. This implies that specific skills with respect to adjusting laboratory equipment are difficult to develop with this experiment and the focus is instead on understanding the concept of quantization through first-hand experience. Students can make four key observations:

1. As the Franck-Hertz experiment is steered by a steering module, students generally only set the maximum accelerating voltage. They then observe, that said voltage increases linearly, which generally happens quite fast.
2. As the accelerating voltage increases, the number of rings indicating excitation zones in the Franck-Hertz tube also increases. The total number of visible rings is, however, limited to four or five.
3. The cathode current shows a distinct shape with extrema and, more importantly, does not increase linearly. Due to the setup of the experiment, the accelerating voltage and the cathode current cannot be simultaneously read off the Franck-Hertz apparatus itself.
4. Using an oscilloscope, the accelerating voltage and the cathode current can be displayed simultaneously, but are sometimes difficult to read, as this requires some experience in working with an oscilloscope. This is not necessarily the case with high school students.

Within the Franck-Hertz experiment, all of the observations above can, at least in principle, be made simultaneously. A true simultaneous observation is, however, hindered by the quite fast increase of the accelerating voltage, which makes it difficult to observe the onset of excitation zones, once a specific voltage is reached.

Using an ultra-concurrent lab allows to tape each of the individual components and to combine them in a side-by-side video for maximum visualization. This way, all or at least most of the observable effects become more feasible for simultaneous observation. A video of this experiment also allows to go back and forth and to pause in order to locate the onset of an excitation zone at a specific voltage.

A shortcoming of a video with respect to analyzing the cathode current is that the maxima of the cathode current and the respective accelerating voltages cannot be accurately read from the oscilloscope. This is, however, only a minor drawback as the full measurement can be provided to the user as a downloadable file once the full video has been watched.

As the Franck-Hertz experiment is relatively expensive it is expected that only one or two setups are available per school. This implies that it cannot effectively be used for experimentation with small groups of students and that the teacher will thus mostly use this experiment for demonstration. Use of an ultra-concurrent lab will allow for small groups of students to work on this experiment, and thus allow for all benefits that come with student-centered experiments. Moreover, an ultra-concurrent lab does not require any setup within the classroom, which means that the work on the experiment can easily be spread over multiple lessons, in case this is required. Furthermore, misleading conclusions by the students or false readings of individual parameters can easily be checked and corrected by re-watching the video.

SUMMARY AND OUTLOOK

This paper presents the efforts of transforming the Quantum Mechanics Venue, into a modern and digital cross-reality lab. The reported efforts commenced by exemplarily creating digital versions of already existing experiments in quantum mechanics. Three experiments (teltron tube, Millikan experiment, Franck-Hertz experiment) were selected for prototypical digitization. Two of the selected experiments (teltron tube, Millikan experiment) were digitized by creating simulated versions of the experiments, whereas the Franck-Hertz experiment was implemented in the form of an ultra-concurrent lab. All three approaches have reached the stage of a mature prototype and will be successively enhanced and finally be tested with students.

In order to create a simulation with appealing graphics, UnrealEngine5 was used for implementation. Three-dimensional simulations with high resolution are expected to raise the interest of the participating high school students, as these engines are well known from commercial computer games. The use of these engines may, at a later stage also be used to introduce elements of gamification into the learning process.

For the Franck-Hertz experiment, the individual components of the experiment were filmed separately and then placed side-by-side in an additional editing step. This approach offers the advantage that the visibility of several visual effects, which happen simultaneously, but are difficult to *view* simultaneously can be increased.

Both simulations and ultra-concurrent labs allow for a decoupling of the learning process from the physical location of the lab and thus increase the possibility for self-organized learning. The remote use of the cross-reality laboratories further equips teachers with the possibility to use these experiments inside their own classroom, in order to replace demonstrator experiments, which provide relatively little student interaction. Use of simulations and ultra-

concurrent labs enables small groups of students and even individuals to conduct these rather complex and expensive experiments on their own. As complicated alignment and possible failures of parts of the equipment do not have to be addressed, these experiments become more plannable from a teacher perspective and might even save time, which can then be used in reasoning on the necessity for a quantum mechanical description, for example. Moreover, the use of the cross reality laboratories will make experimentation more inclusive, as small effects, which are difficult to see for persons with impaired vision, can easily be enlarged on a screen.

In summary, one finds that simulations and ultra-concurrent laboratories are well suited for the use in a learning teaching lab on quantum mechanics. It offers a different experimental perspective for high school students visiting the lab, and provides teachers with a wider range of possibilities on the implementation of these experiments in their teaching. It further facilitates the learning of university students, which are given the opportunity to obtain a significantly enhanced knowledge on digital teaching – a highly valuable skill in a digitized world. Cross reality labs are therefore very useful to complement the hands-on experiments in learning-teaching laboratories, as they enhance the overall learning possibilities provided by this specific type of laboratory. They are, however, not meant to replace hands-on experiments as these require a different set of skills and offer a different set of experiences. And, lastly, the use of cross-reality labs should of course align with the learning goals set for the students.

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NAVIGATING THE AI ERA: ANALYZING THE IMPACT OF ARTIFICIAL INTELLIGENCE ON LEARNING AND TEACHING ENGINEERING PHYSICS

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This paper delves into the impact of artificial intelligence (AI) on learning and teaching engineering physics, focusing on the use of AI chatbots. The study explores various issues encountered by educators when students utilize AI to solve physics problems, highlighting potential pitfalls and opportunities. Through testing AI chatbots' capabilities in physics learning, the paper evaluates their effectiveness in providing accurate and insightful responses. Results indicate that while AI, especially ChatGPT 4, shows promise in aiding students' understanding of physics concepts, there are limitations and challenges to consider, such as over-reliance on technology and the potential for AI to produce misleading solutions. The implications and discussions underscore the need for a balanced approach in integrating AI into education, emphasizing authentic understanding over merely obtaining correct answers. Using AI in creating teaching materials is not evaluated here.

Keywords: Artificial Intelligence, physics teaching, physics learning.

INTRODUCTION

Artificial intelligence (AI) has emerged as a transformative force, reshaping industries, societies, and the way we live our lives. AI involves the development of computer systems capable of performing tasks that traditionally require human intelligence [1]. These tasks include learning, decision-making, language understanding, and visual perception. The significance of AI in today's world cannot be overstated, as it drives innovation across fields ranging from healthcare and finance to transportation and education. Educators and learners already use AI technologies like search engines, smart assistants, chatbots, translators etc. in their daily life, sometimes even without realizing it. There are high expectations for the use of artificial intelligence, and it is expected to transforming learning for the 21st century by providing personalized, accessible, and efficient educational experiences [2].

The European Union has published report of the impact of AI on learning, teaching, and education [3] and ethical guidelines for using AI [4]. These documents explore the transformative impact of AI on learning, teaching, and education, highlighting both opportunities and challenges. The rapid pace of technological change is emphasized and the need for educational practices, institutions, and policies to adapt to the changes. The reports address the potential of AI to revolutionize educational approaches through personalized learning, efficient resource use, and data-driven decision-making, while also considering the technical, and practical aspects of integrating AI into education. Also, the need for ethical considerations in the deployment and use of AI and data in education is emphasized. Key requirements for trustworthy AI include transparency, non-discrimination, privacy, and accountability. Educators are guided to ensure AI systems are reliable, fair, safe, and protecting individual privacy, promoting a responsible and ethical approach to incorporating AI technologies in educational settings. Many higher education institutions have written their own guidelines for using AI in educational settings. For example, Tampere University of Applied Sciences encourages students, teachers, and staff to familiarize themselves with and utilize AI

systems in education, such as for information retrieval and to get ideas for content creation. Ethical and responsible use of AI applications is emphasized, with students always responsible for the content of their assignments and required to critically evaluate AI-generated content alongside other sources.

In the educational sector, artificial intelligence is revolutionizing the learning experience by offering personalized teaching solutions and efficient administrative support. For instance, the Georgia Institute of Technology introduced a virtual teaching assistant, Jill Watson, to handle frequently asked questions, enhancing the efficiency of the teaching staff [5]. Similarly, platforms like Duolingo and Khan Academy leverage AI to adapt learning experiences to individual student needs, demonstrating AI's capability to make learning more engaging and tailored. In the next chapters the scope is narrowed down to the use of AI, especially AI-chatbots, in bachelor's level engineering physics learning and teaching. Various issues that a teacher encounters when students utilize AI to solve physics problems are discussed. Examples illustrate how AI-assisted answers differ from traditional student responses, highlighting issues such as over-reliance on technology, lack of fundamental understanding, and potential discrepancies in problem-solving approaches.

AWAKENING TO CHAT-GPT ERA

Tampere University of Applied Sciences (TAMK) offered a thermodynamics course in 2023. During the course the student answers to open-ended homework questions started to be bizarre. Here is one example: the students were asked to tell and describe some isochoric processes in their everyday environment. The answers told about car and pedestrian traffic in a junction, a forest ecosystem with numerous species and their interactions, a gas stove that have a high temperature and can heat several foods at the same time on different hotplates etc. In these cases, students had clearly used ChatGPT or similar AI tool without any own effort to analyze the answer and estimate its correctness. Unfortunately, these are also nice examples of AI hallucinating: generation of information that is incorrect and misleading, presenting it as if it were true. This phenomenon can manifest as deviations from factual accuracy, logical coherence, or both, often appearing plausible due to the LLM's (large language model) design to produce fluent and coherent text despite lacking an understanding of the underlying reality the language describes.

The language used affects the results in AI-chatbots. In the previous example, the language was Finnish. Also, the learning process of the AI-engine became nicely visible – after getting those bizarre answers, the teacher himself tested the ChatGPT with the same question (in Finnish) the result was the following:

ChatGPT:

"Valitettavasti termi "isokoorinen" ei ole minulle tuttu, ja se saattaa olla erikoistunut tai rajoitetusti käytetty termi. Voitko tarjota lisää tietoa tai määritellä, mitä tarkoitat isokoorisella prosessilla?"

Translation: *"Unfortunately the term "isochoric" is unfamiliar to me and may be a specialized or restricted term. Can you provide more information or define what you mean by isochoric processes?"*

When the same term was given in English to ChatGPT, it made the connection and learned what "isokoorinen" (Finnish) means. This was the answer:

ChatGPT: *"Ah, nyt ymmärrän. Pahoittelen aiemman epäselvyyden. Isochoric process tarkoittaa tilaprosessia, jossa tilavuus pysyy vakiona…"*

Translation: *"Ah, now I understand. I apologize for the earlier confusion. Isochoric process means a state process where the volume remains constant...."*

TESTING AI CHATBOTS' CABABILITIES IN PHYSICS LEARNING

To find out how far a student can get with using AI chatbots, a few different types of physics questions were presented to four AI bots: OpenAI ChatGPT 3.5, OpenAI ChatGPT 4, Microsoft Copilot and Google Gemini. It should be noted, however, that the answers reflect the situation in February-March 2024 – the speed of AI development is very fast, and the results are likely to get better on monthly basis.

Question 1: Thermodynamics. Presented in Finnish, here only translation:

"There is ice in a thermally insulated container at a temperature of -20 °C. The interior of the container is heated with a constant power P. It is assumed that the heat is distributed inside the container with infinite efficiency and that the container is perfectly insulated. The heating is continued until the ice has melted, and the water formed from the ice begins to boil. The pressure in the container remains constant. Sketch a graph of the temperature of the container as a function of time."

All chatbots provided text answers that sounded convincing to a layman. Only ChatGPT 4 was able to produce a diagram, whereas the others offered a written description of the diagram. Fig.1 presents the interpretations of the text answers and the actual graph (ChatGPT 4).

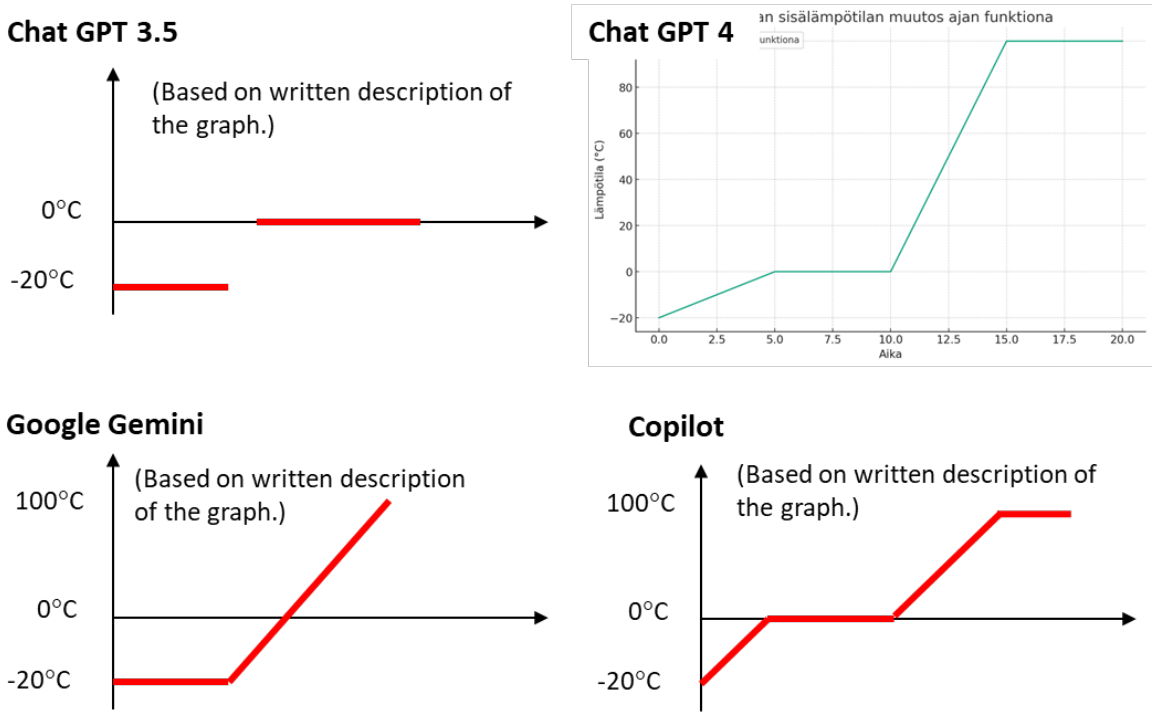

Fig.1. The results of chatbot text answers interpreted to graphs. For ChatGPT 4, the graph is real and created by the AI chatbot.

There were inaccuracies and aspects missing in all answers. ChatGPT 4 did best, it was able to create the graph and it showed even the different slopes of temperature change for heating ice and water – however, the slopes are not correct. All answers also quite correctly presented the equations needed for different parts of the graph. Despite the correct equations, only ChatGPT 4 was actually able to provide the diagram, whereas the others responded with written description. It is clear that Google Gemini and ChatGPT 3.5 are not yet sufficient tools for this type of learning. Copilot's answer was partially right, but it still lacks the ability to draw the graph and didn't mention different slopes of temperature change for ice and water.

Question 2: Mechanics. In English.

"What are the forces acting on a car travelling on a horizontal road at a constant speed?"

To this question, all chatbots provided rather correct text answers and included the idea of net force being zero. The forces were correctly named, and they were explained. In some cases, there were somewhat misleading descriptions of the friction: the effects of rolling friction and friction needed to create the traction were mixed, omitted, or misleadingly presented depending on the bot. Also, normal force was not separately presented for the front and rear wheels and directions and points of action of the forces were not very well described. In this sense the answers represented an average engineering student quite well. The summary of answers is presented in the figure 2. None of the bots was able to create a correct free body diagram. Only ChatGPT 4 (Dall-e) created any image, but it was an artistic illustration of a car rather than a real physics free body diagram. When the setting is reversed and the free body diagram was uploaded to a chatbot, most of them were able to interpret it correctly and tell about the forces present.

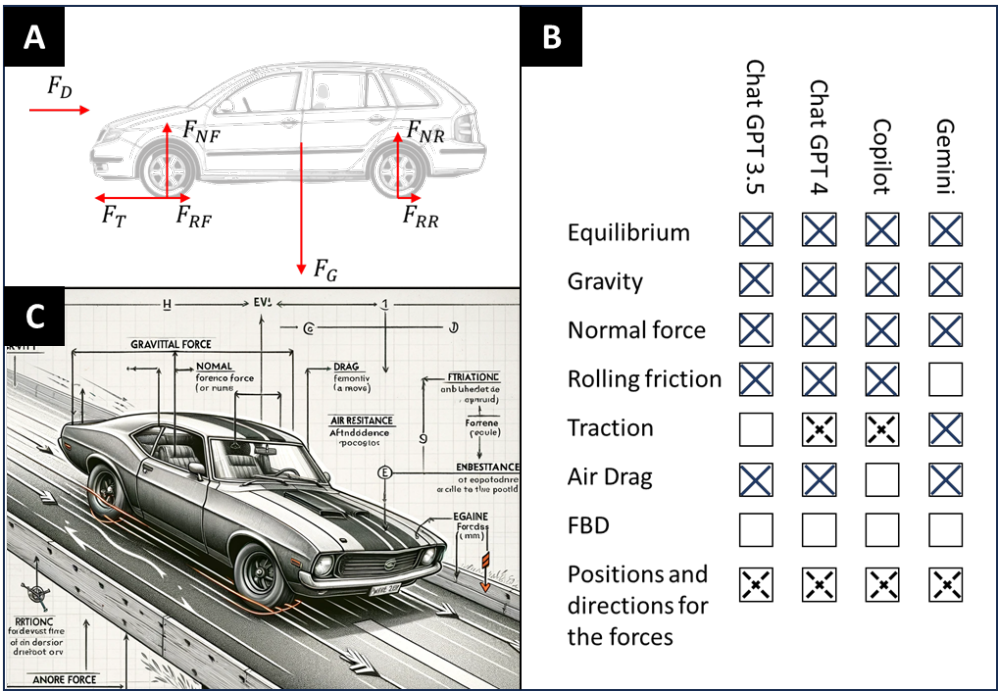

Fig. 2. The results of asking the chatbots to describe the forces acting on a car travelling on a horizontal road at a constant speed. A) The expected answer and forces, B) Chatbots' answers' correctness, and C) the "Free body diagram" drawn by chatGPT 4.

Question 3: Thermodynamics. In Finnish.

A photo of a typical, somewhat erroneous, handwritten student answer (Fig.3) was given to all chatbots with the question “Is this calculation correct?”. In the problem the student needed to calculate the final temperature and volume for adiabatic compression with the given initial values. It was possible to upload the picture to ChatGPT 4, Copilot and Gemini, whereas ChatGPT 3.5 is not capable to handle attachments. These three chatbots analyzed the answer but the accuracy and correctness varied in the following way:

ChatGPT 4: Correctly pointed out that the temperature is right but there is a mistake in the equation for the final volume. It provided explanations and showed the right equation in an understandable format. It also calculated the right final volume.

Copilot: Only checked if the numerical values were in accordance with the equation used by the student but did not recognize that the equation itself was incorrect. Also, it gave the equations in the following LaTeX format which is not so easy to read as such, but can be visualized with an online LaTex equation editor:

“T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{{\gamma - 1}}{\gamma}}”

Gemini: Hallucinated badly. It said that the student answers were wrong but was incapable of providing the right answers. It showed some equations that were incorrect and gave wrong final answers based on them.

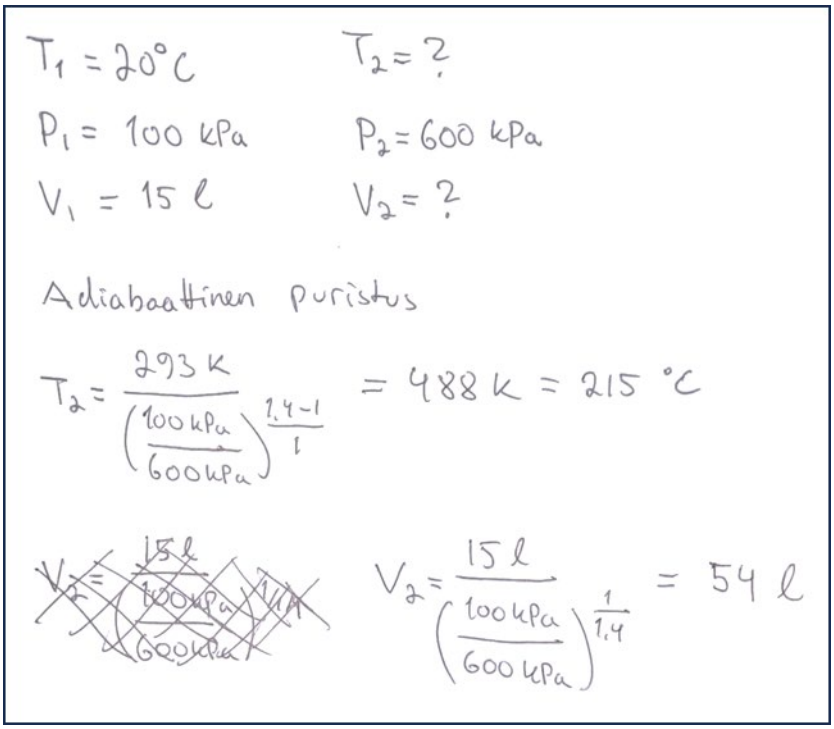

Fig. 3. This photo of a typical, somewhat erroneous, handwritten (student) answer was given to all chatbots with the question “Is this calculation correct?”.

Questions 4-16: Thermodynamics. In Finnish.

Here not all the questions are presented, but instead the result of the test. A bachelor’s level engineering thermodynamics course’s final exam questions (altogether 13 questions) were given to ChatGPT 4 and the answers were then evaluated and graded as if they were provided

by a student. In some questions, the bot needed a value from a table or a graph and these were also then given as inputs. The score was 21 points out of 30 which yielded the final grade of 3 (average, on a scale 1-5). This is in accordance with the previous example (question 2) in which the chatbot answers also represented average engineering student answers. Here, the language (Finnish) did not play any significant role: when the same questions were translated into English and given to the chatbot, it only got one point more (22 points). In the Finnish version it interpreted one temperature difference in wrong direction, and this did not happen in the English version.

IMPLICATIONS AND DISCUSSION

In the landscape of bachelor's level engineering physics education, the advent of AI chatbots offers a dichotomy of educational empowerment and potential pitfalls. The ability to leverage AI chatbots for immediate clarification, formula derivation, and problem-solving walkthroughs could potentially transform study sessions into highly efficient learning experiences for the students. AI chatbots can provide immediate explanations to students' queries, which is particularly beneficial when studying independently at home. Students can ask for clarifications on concepts they find difficult and get instant, detailed explanations. In the future, AI will most likely be incorporated into learning management systems and AI can recommend personalized learning paths, based on a student's performance and preferences. This way, it is possible to reinforce student's weak areas identified for the student with additional resources such as videos, articles, or problems focusing on particular concepts.

For numerical problems, AI could potentially guide students through the problem-solving process step by step. Instead of giving away the answer, it can prompt students with leading questions that stimulate critical thinking and guide them to the solution. Students can use AI to check their answers. If the answers do not match, AI can hint at where a student might have gone wrong, prompting them to review their calculations or understanding of the underlying principles. With AI tools capable of plotting graphs and visual representations, students can better understand the relationship between variables in a problem. AI can assist students in deriving and manipulating equations required for solving physics problems. It can also help students understand when and how to apply different equations to different types of problems.

In general, if the students use AI to clarify a concept or solve a problem, they should nevertheless reflect on what they've learned and try to explain it back to the AI or in a study group to reinforce their understanding. Students should apply the concepts they learn with AI to new and varied problems or real-world scenarios to solidify their understanding and ability to generalize the knowledge. Engaging in online forums or study groups to discuss the AI-provided solutions can enhance understanding and expose students to different ways of thinking about a problem.

However, there exists a concern for students becoming over-reliant on AI, leading to a superficial understanding of complex physics concepts. AI's current limitations, such as producing plausible yet factually incorrect solutions, could reinforce misconceptions. Students should also be made aware of the ethical use of AI, ensuring that while AI can assist in learning, the integrity of their work remains intact, and they do not pass off AI-generated solutions as their own without understanding.

For educators, AI promises to enhance teaching efficiency, teaching material production and curriculum design. Teachers can for example use AI to produce large sets of multiple choice questions to a certain topic, which reduces teacher's work load. Or they can make illustrative pictures for teaching materials using AI by first drawing a simple sketch with pen and paper

and then asking the AI to make an improved version. At the moment, there are some limitations: the produced images are more artistic than schematic. Therefore, teacher might need to add vectors, texts etc. to the AI-generated image.

An AI assistant like Jill Watson at Georgia Tech can manage routine inquiries, freeing up valuable time for educators to engage in deeper pedagogical activities. Yet, integrating AI into teaching requires a recalibration of assessment methods and educational goals. Teachers must now consider how to effectively evaluate students' mastery of physics, distinguishing between genuine understanding and AI-assisted work. They also face the challenge of fostering an environment where students balance the use of AI tools with the development of critical problem-solving skills. Pedagogically, it is vital to foster an educational ecosystem where AI is viewed as one of many tools that enhance learning. AI should complement, not replace, the nuanced feedback that only human interaction can provide. Regular student-teacher discussions can help contextualize and correct AI-generated content. Both students and educators must remain literate in AI's capabilities and limitations, understanding its evolving nature and potential biases in its generated content. Evaluations might need to adapt, focusing less on memorization and more on understanding, applying, and synthesizing knowledge in novel situations—skills less replicable by AI.

Incorporating AI into the process of solving homework problems and answering graded assignments at home requires careful consideration to ensure that it enhances, rather than detracts from, the educational experience. The key is to structure assignments in a way that the use of AI becomes a part of the learning process, rather than a shortcut to the finish line. Assignments can involve complex, multi-step problems where AI may provide guidance on individual steps, but the student must understand how these steps connect and lead to the final solution. Shift from traditional problem sets to open-ended projects where AI can be used for initial research or generating ideas, but the final product requires a unique and creative application that reflects the student's understanding. Provide students with custom datasets or unique problems that cannot be directly answered by AI, requiring them to apply concepts learned in class to analyze the data and derive conclusions. Focus on grading the process rather than the final answer. Students submit drafts, revisions, and reflections on their problem-solving process, detailing how they utilized AI as a tool in each step.

Based on the tests presented in the previous chapter, ChatGPT 4 and Copilot can be recommended to students as learning aids and personal tutors. However, it is important to emphasize potential inaccuracies and other pitfalls of the chatbots and showing some incorrect examples to the students to make it clear that they cannot rely solely on the chatbot results. Instead, they should always consult also other sources. For graded assignments, teachers should bear in mind that AI chatbots can provide answers to physics problems at the level of an average student at the moment. Therefore, care should be taken when planning unsupervised graded assignments.

SUMMARY

Based on the tests described above, only ChatGPT 4 seems to be advanced enough to be used as a personal tutor in learning physics at the time of writing this paper. At the moment, other common AI-chatbots lack some abilities or hallucinate in answering questions which limits their use in learning. Educators must emphasize the importance of authentic understanding over simply obtaining the correct answer. By fostering an environment where AI is used to aid the learning process and by designing assignments that require personal input, reflection, and critical thinking, students can effectively use AI without forfeiting the

development of their own knowledge and skills. This balance ensures that students are not just trained to solve problems but are truly educated to understand the physics behind them.

In summary, AI can be a powerful tool for students learning at home, offering personalized support and enhancing both conceptual understanding and problem-solving skills in learning physics. However, it is crucial that students use AI responsibly, ensuring that they do not become overly reliant on it and that they critically engage with the material to achieve genuine comprehension. The future of education lies not within AI itself but in our ability to integrate its strengths with the irreplaceable elements of human creativity, critical thought, and ethical consideration.

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THE ROLE OF LEARNING SPACE IN ENHANCING ACTIVE LEARNING: INTRODUCING THE STEM-CENTER AT TAMPERE UNIVERSITY OF APPLIED SCIENCES

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This paper describes the transformation of engineering physics education through activating teaching methods for better learning outcomes and the redesign of learning spaces to support these pedagogical approaches. The transformation of a traditional physics laboratory into a versatile group work and multipurpose space known as the "STEM-Center," at Tampere University of Applied Sciences is presented. The transformation was inspired by active pedagogical methods such as "Peer Instruction," "PDEODE," and the "SCALE-UP" method and its associated spaces. After the transformation, the space remains suitable for physics laboratory work. Across all courses, it encourages students to be active participants rather than passive listeners, which in turn improves learning outcomes. Most students express high satisfaction with the pedagogical methods and the learning environment as well as a preference for these engaging and activating methods over traditional lecture-based teaching, highlighting an enhanced learning experience and a stronger sense of ownership over their learning.

Keywords: Learning space, groupwork, activating methods.

INTRODUCTION

Engineering physics combines theoretical concepts of physics, the laws of physics, and their practical applications in everyday life, in machines, devices and measurements. This requires teaching methods that go beyond traditional lecture-based approaches. In recent decades, the emphasis has shifted towards more participatory and student-centered approaches and activating teaching methods.

The concept of active learning encompasses a broad range of practices that promote student engagement, critical thinking, and a deeper understanding of course contents. Unlike passive listening to lectures without direct participation, active learning encourages students to participate actively in their education through discussions, problem-solving, group work, and other interactive methods. Different studies have highlighted benefits of active-engagement learning methods. Prince [1] has found support for all forms of active learning examined in his studies. Freeman et al. [2] carried out a meta-analysis of 225 studies that had reported course scores and passing rates in STEM courses, and they compared results of studies between traditional lecturing method and active learning methods. Their analysis indicated that using active learning methods can increase passing rates and course scores. Deslauriers et al. [3] has show improved learning outcomes in a large-enrollment physics class when using pre-class reading assignments, pre-class reading quizzes, in-class clicker questions with student-student discussion, small-group active learning tasks and targeted in-class instructor feedback. Especially, they found that active learning methods have great benefits with small groups, but it is effective for all group sizes. Wieman has found similar positive effects [4]. In addition to active-engagement methods, also self-regulatory skills are also often connected with active learning. Research has shown that when mastering own learning process and feeling the ownership of learning, learning outcomes are typically better [5, 6].

The physical and virtual environments where learning takes place play a crucial role in facilitating or hindering active learning practices. Learning spaces include traditional classrooms, digital platforms, laboratories, libraries, and any other environments where learning occurs. The design and organization of these spaces can significantly affect students' ability to engage actively with the material, their peers, and their instructors. In physics learning and teaching, the space should accommodate various teaching methods and learning activities, including group discussions, individual study, and hands-on experiments. Therefore, the layout and furniture should be easily reconfigured for different activities. Modern learning spaces incorporate ICT technology to facilitate access to information, collaboration, and interaction both onsite and online. Designated spaces for group work and collaboration encourage students to work together, share ideas, and learn from one another, which is a key aspect of active learning. Research has shown that well-designed learning spaces can have a positive impact on student engagement, motivation, and learning outcomes. A study by Cotner et al. [7] found that students in classrooms designed for active learning reported higher levels of engagement and better understanding of course material compared to those in traditional lecture-based classrooms.

While the benefits of learning spaces designed for active learning are clear, there are challenges to their implementation. These include the cost of redesigning physical spaces, the need for faculty training on how to effectively use these environments, and the ongoing maintenance of technology and furniture. Additionally, the transition to more active learning spaces requires a cultural shift within educational institutions, moving away from traditional lecture-based teaching methods toward more student-centered approaches. Beichner and Saul demonstrated the impact of the SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs) classroom design on student performance and engagement in physics education, highlighting the importance of physical space in promoting active learning strategies [8].

The next chapter describes the transformation of a traditional physics laboratory at Tampere University of Applied Sciences (TAMK) into a versatile group working and multipurpose space known as the “STEM-Center”. The transformation was inspired by active pedagogical methods such as the above mentioned "SCALE-UP" method and its associated spaces and other methods like "Peer Instruction" [9] and "PDEODE" [10]. These methods are explained in more detail later. The focus is on how the learning space and its facilities can enhance the use of active learning techniques, and how students receive activating methods.

FROM PHYSICS LABORATORY TO STEM-CENTER

A few years ago, one of the physics laboratory spaces was transformed into an engaging group work and multipurpose space. This STEM-Center is used to deliver engineering degree education, vocational teacher education, international degree education, continuous learning, and pedagogical training courses. After the transformation, the space still remains suitable also for physics laboratory work. Across all courses, it encourages students to be active participants rather than passive listeners, which in turn improves learning outcomes.

Active participation and knowledge processing are the cornerstones of effective learning. The goal was to create a classroom environment where students are constantly interacting with the material, engaging in group work, reflecting on phenomena, sharing their outputs, and applying concepts in different contexts. Group work serves as a platform for collaborative problem-solving and idea exchange. It reflects real-world scenarios where engineers often work in teams to solve complex problems. In this environment, students learn to articulate their

thoughts, listen to alternative perspectives, and develop solutions together. Group projects and laboratory work are typical examples where students can apply theoretical knowledge to practical tasks, enhancing their understanding of physics concepts. Additionally, group work helps develop soft skills such as communication, teamwork, and leadership, which are crucial in professional engineering roles.

Figure 1 shows the room as a traditional physics laboratory before the transformation (A), the initial sketch of the desired outcome (B) and the realized outcome (C). The plan was inspired by SCALE-UP layout with additional option for laboratory working. Before the transformation, the laboratory typically accommodated 16-24 students simultaneously. Now there are group work tables for 36 students and additional 10 seats near the windows. Unfortunately, both budget and structural limitations changed the plan in such a way that it was impossible to remove the wall between the corridor and the former laboratory room (Fig. 1 C). Also, the glass wall between the STEM-Center and the adjacent laboratory room had to be left out. Despite these limitations, the space now has facilities for group working and laboratory working, sharing of outputs both onsite and online, and streaming the teaching and measurements online.

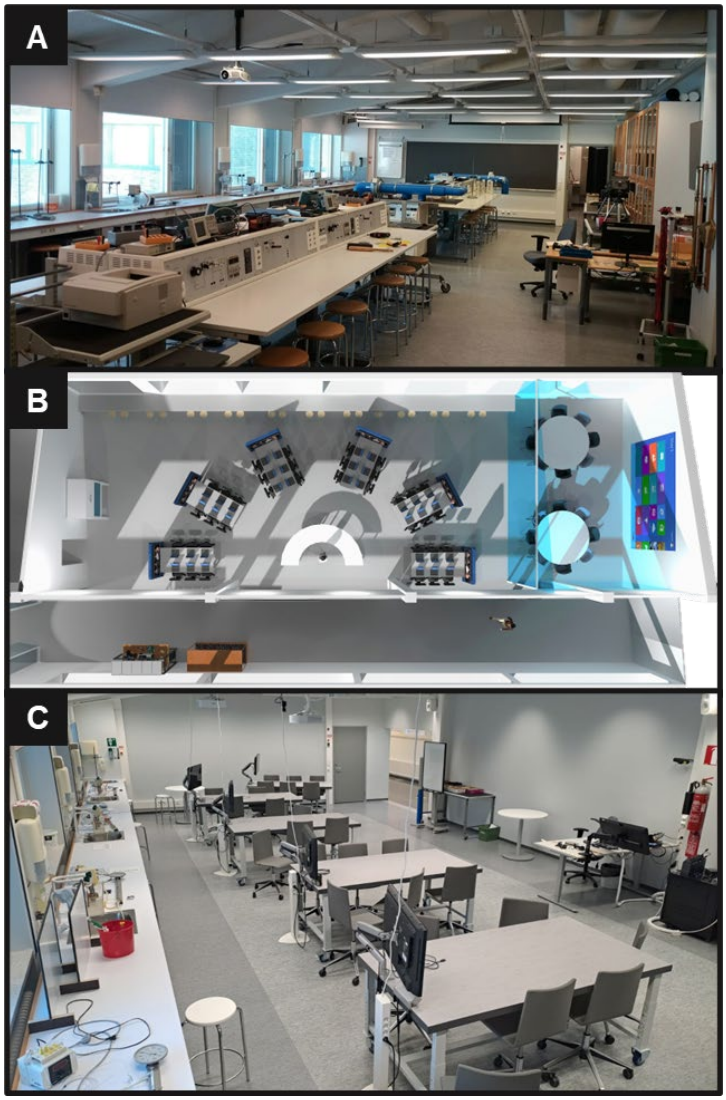

Fig. 1. The space initially as a physics laboratory (A), the sketch for modifications (B), and the actual output, the space as STEM-Center after the renovation (C).

PEDAGOGICAL METHODS

Unlike traditional classroom teaching, STEM-Center fosters student-centered and active learning where theory and practice are both present. One pedagogical method used in engineering physics at TAMK is peer instruction, developed by Harvard professor Eric Mazur in the 1990s (Mazur, 1999). It emphasizes collaborative learning through peer interaction. In this approach, students engage in discussions with their peers to grapple with challenging concepts and solve problems collectively. By explaining concepts to their peers or engaging in peer-led discussions, students not only reinforce their understanding but also develop communication and critical thinking skills. This collaborative environment fosters a sense of shared responsibility for learning, promoting a deeper understanding of engineering physics principles.

In a typical peer instruction situation, the teacher poses a conceptually challenging question, students initially ponder the question individually, and then they discuss their thoughts with their peers. This method not only promotes deeper understanding through discussion but also allows students to teach and learn from each other, promoting a collaborative learning environment. Mazur's approach has proven to be particularly effective in elucidating complex physics concepts, enabling students to explore and correct misunderstandings through peer discussions. Another method, PDEODE (Predict, Discuss, Explain, Observe, Discuss, Explain), expands Peer Instruction with the observation phase. After pondering the phenomenon individually and in small group, the students actually observe a measurement or a demonstration of the topic. Then they (re)form their understanding of the topic again. One version of this PDEODE method is simple measurement assignments for enhancing active participation and building of conceptual understanding of the topic [11]. These measurement assignments also serve as one method of continuous formative assessment.

In all above-mentioned pedagogical methods, the key issue is to first make own understanding visible (by sketching, explaining etc.). Then, the understanding needs the presented and shared with peers. With the help of the learning environment's technology, the outputs, ideas, and thoughts produced by student groups can be easily shared digitally for further discussion. The teacher can easily facilitate the independent work of student groups. The monitors at the group workstations help small groups work together, processing the same data or working on presentations (Figure 2).

Fig. 2. Students working in small groups and sharing the output within the group.

Simultaneous sharing of learners' outputs is possible with three projectors. One projector image can be divided into four equally sized areas, each of which can be shared from one computer screen using a wireless transmitter (Figure 3 insert). With these transmitters and projectors, it is possible to simultaneously display the outputs of eight groups with two projectors and compare or discuss them (Figure 3). For laboratory working, all necessary equipment and devices are stored in the room or in its immediate vicinity (Figure 4).

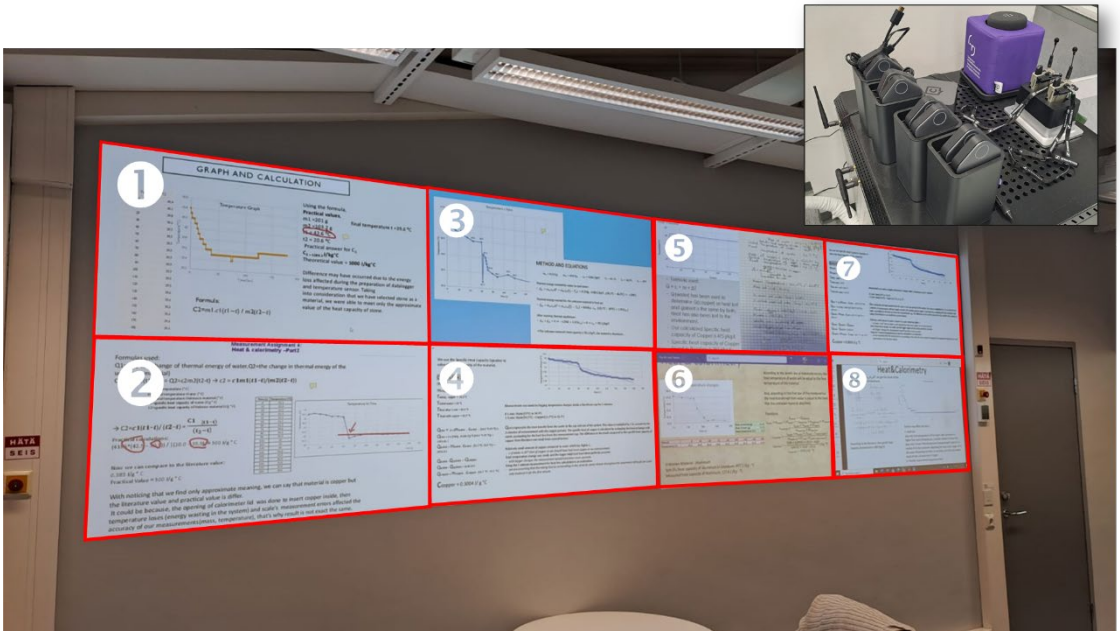

Fig. 3. Using the wireless transmitters (insert) it is possible to simultaneously display the outputs of eight groups with two projectors and compare or discuss the results.

Fig. 4. For laboratory working, all necessary equipment and devices are stored in the room or in its immediate vicinity.

STUDENT FEEDBACK AND TEACHER EXPERIENCES

Teaching held in the STEM-center space mainly consists of laboratory work and smaller measurement tasks supporting theoretical courses. Teachers' experience of the space is that it works well in both roles. Monitors for group workstations allow small groups of people to work together, processing the same data or making a presentation. Simultaneous sharing of learners' outputs is possible. The space is spacious enough so that group work can also be done while taking measurements.

Feedback was collected from one student group. There were 24 answers from 36 students. It consisted of open-ended questions and statements on 5-point Likert scale. The statements and the answers to them are shown in the figure 5. By first analyzing the open-ended feedback, the following aspects can be highlighted:

- 80 % of the responses mentioned the effectiveness and appreciation for practical, hands-on learning, measurement tasks, and the application of physical principles in real-world scenarios.
- 63 % of the responses highlighted the positive aspects of the course's structure and learning approach, including the practical method of teaching, interesting classes, and the versatile grading method consisting of measurement tasks and exams.
- 13 % of the respondents recommended refining assessment methods to better gauge individual learning outcomes instead of having a heavy weight on group working results.

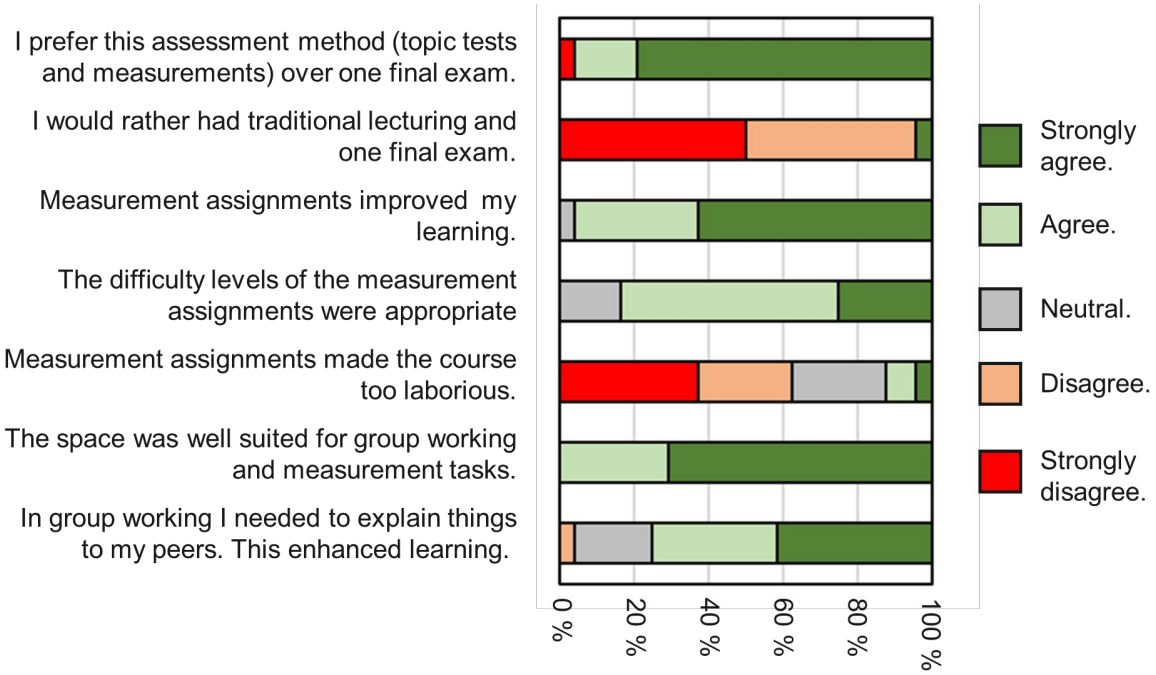

Fig. 5. The statements and the answer distributions to them.

The results indicate high satisfaction with the pedagogical methods and the learning environment. Vast majority of students express a preference for these engaging and activating methods over traditional lecture-based teaching, highlighting an enhanced learning experience and a stronger sense of ownership over their learning. Based on the responses, students are quite

satisfied with pedagogical methods and measurement tasks. They felt that both experimental measurement and visualization and group work improved their own learning. Only very few would like to return to traditional lecture-style teaching and a single final exam. Instead, almost all respondents supported engaging methods.

SUMMARY

In conclusion, activating methods and peer discussion-enhanced active learning play a crucial role in enhancing learning outcomes in Bachelor's level engineering physics education. By fostering active engagement, deepening understanding, promoting skill development, facilitating retention and enhancing motivation and engagement, these methods empower students to become active participants in their learning journey. A student response to open-ended feedback question summarizes it well:

"After taking this course, I felt that I never had a real physics course before. I enjoyed it a lot. Also, it made me feel that I will become an engineer one day, hopefully."

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A NEW MODEL TO REALIZE PHYSICS TEACHING IN TAMPERE UNIVERSITY OF APPLIED SCIENCES

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In Tampere UAS the physics and mathematics education will be organized in a new way. The new model increases flexibility for students to choose a learning method suitable for them. The new model also offers some strong support for those students that are at the greatest risk to underperform or drop out their studies. The flexibility includes a possibility for an asynchronous online implementation in every physics and mathematics course. The stronger support means some extra workshop lessons for those who are in danger of dropping out. These workshop lessons concentrate on the very basics of the subject matter.

Keywords: Blended learning, flexible education

INTRODUCTION

In Finland, universities of applied sciences (UAS's) have two main roles, education and research and development (R&D). UAS's get most of their funding from the Finnish Ministry of Education. The funding is based on a funding model described in Fig. 1 [1]. In the funding model the most important part is the number of graduated bachelors that graduate on time representing 56 % of the total funding. This means that for a UAS it's essential to get students to advance their studies smoothly. It's also clear that there should not be too many dropouts during the years of studying.

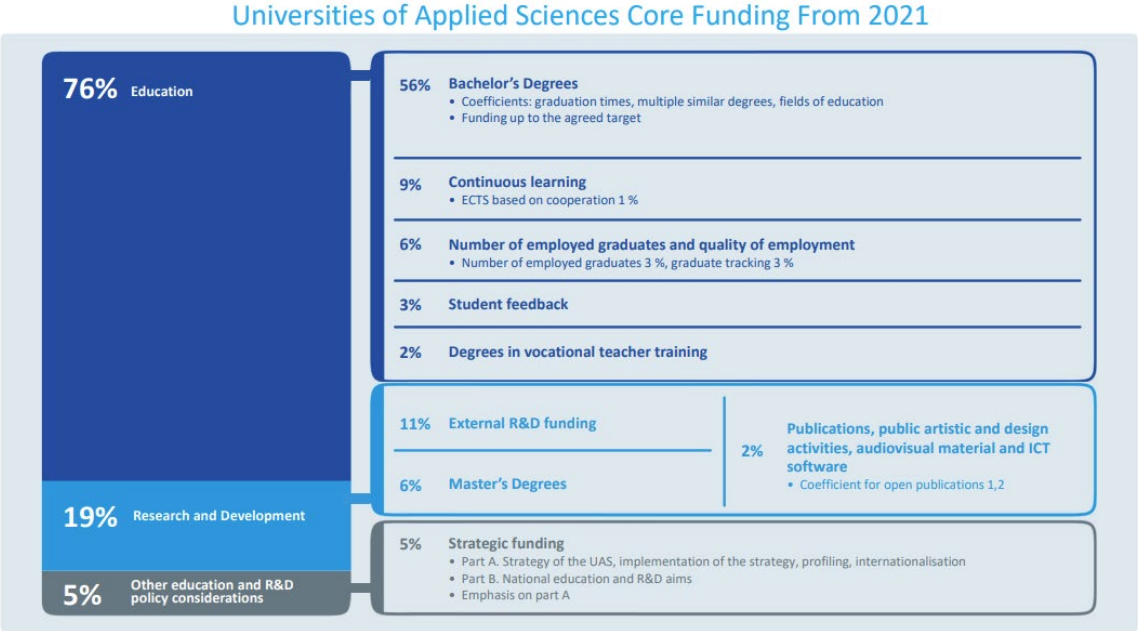

Fig.1. Funding model of Finnish UAS's. [1]

At the same time, the students entering to UAS's are very diverse in terms of skills in learning and prior knowledge in mathematics or physics. Depending on the UAS, almost a half of freshmen students have a vocational education background, which means a total amount of 15 (phys.) + 60 (math.) hours of physics and mathematics at the secondary level of education. The other end of the spectrum are those students who have studied hundreds of hours of physics and mathematics at the upper secondary school.

The expected learning outcomes of the UAS introductory physics are the same for all students, so both diversity and the lack of previous skills must be considered in the planning process of the UAS physics education. Physics studies are usually scheduled during the first year of studies, when the risk of dropping out is the highest.

Physics and mathematics are also considered to be difficult subjects to study. Engineering students entering the UAS have a focus on studying a specific branch of engineering and the heaviness of the physics and mathematics studies in the beginning may be crushing.

DEVELOPMENT

In Tampere UAS the physics and mathematics studies will be implemented with a new model that offers flexibility for students as a whole and offers some support for those who are at the biggest risk of underperforming. In the model the main path of teaching and learning are blended course implementations of 40 – 80 students. The implementations will be carried out using active engagement blended learning based mainly on the model presented in [2] and [3] and is shortly described later. Blended implementations have a slight weighting depending on the engineering branch that a student studies. This means that examples and applications are chosen inside the branch e.g. construction or mechanical engineering, if possible.

As an improvement to the earlier, in every course unit, there will be an asynchronous fully online implementation running aside, which is common to all branches of engineering. So those students who have better previous skills than others, can study online and faster. In online implementation the weighting according to the engineering branch is lighter than in blended one. Online implementations follow the same pedagogical approach described later.

The second improvement is a stronger support for those students who find that they are facing major difficulties in their studies. They will have 1 – 2 weekly hours of extra contact teaching. The extra contact teaching is focused on the very basics, so it aims at the lowest possible grades only. The picture of the model is presented in the Fig. 2.

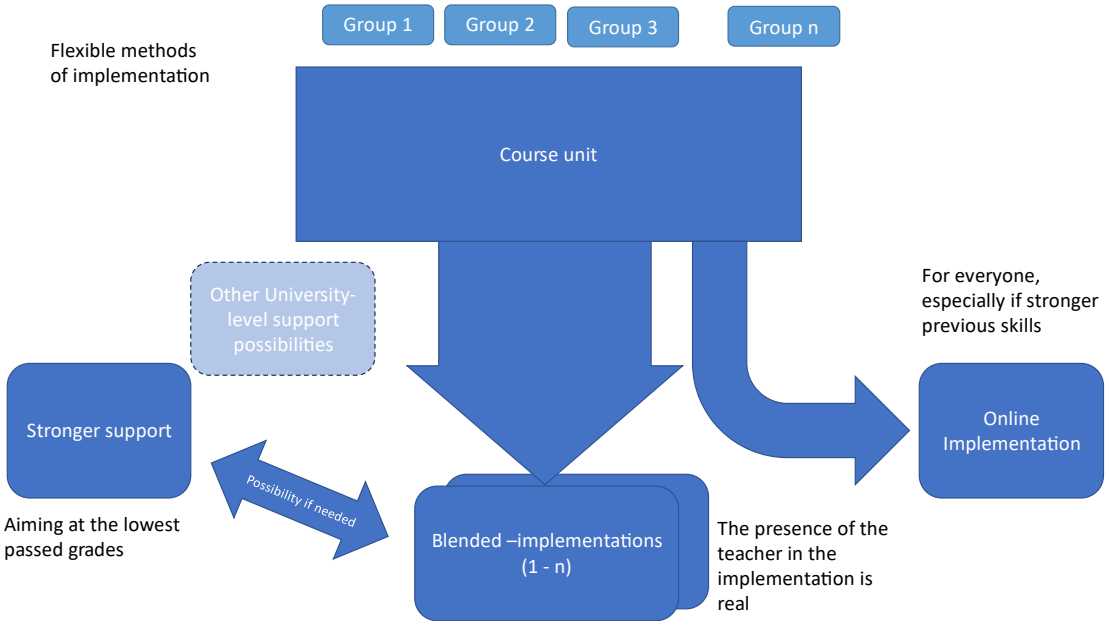

Fig.2. The new model.

The pedagogical approach followed in every part of the model is based on common physics active engagement models like Flipped classroom including Just-in-Time teaching [4] combined with Peer Instruction [5]. The pedagogical approach follows the ongoing model of physics teaching in Tampere UAS. In the approach, studies proceed based on weekly schedule and weeks end to a week exam or measurement assignment, which are assessed. There weekly tasks can produce as much as 50 % of the assessment points. The rest of the points are based on the final exam after the course. The approach and its continuous assessment has gathered some very good feedback from students. The basic idea of the approach is described in Fig. 3.

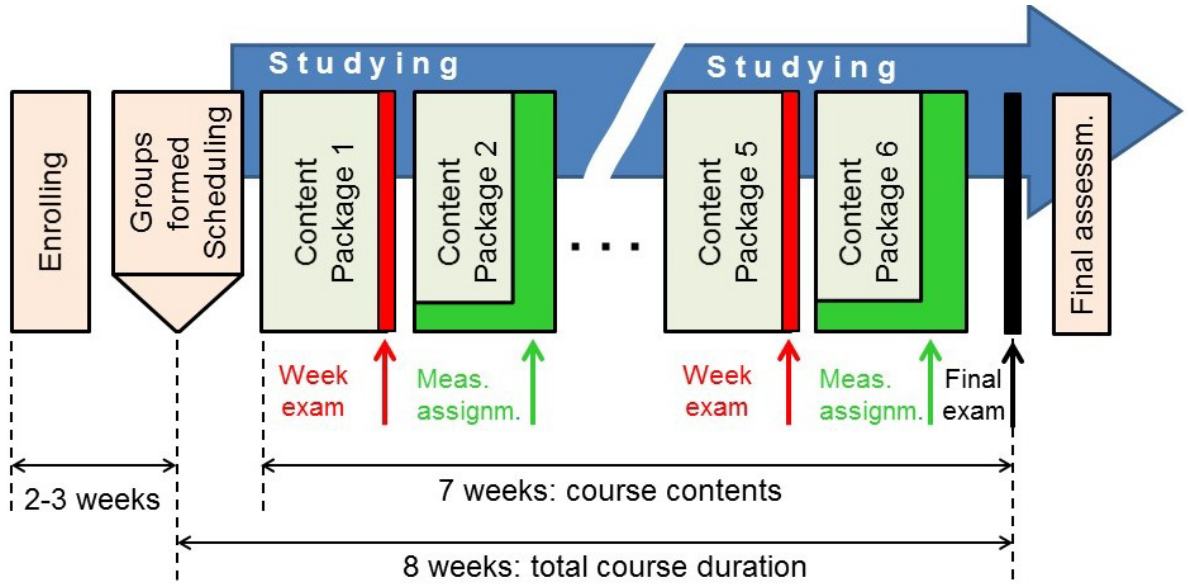

Fig.3. Basic model of a blended course.[6]

In the new model, there will be more effort towards students' own practicing. The technique to advance this will be Moodle's Stack questions. The Stack questions are questions that can randomize the initial values of the calculations and they can be automatically checked. They also include a possibility to give feedback if the answer goes wrong in a typical way. It is also under consideration that the lowest possible would be achievable with automatically assessed weekly exams or baseline exam that students can attempt as many times as they like. The questions and their initial values would be randomized in a reasonable way. Some experiences of this have been reported in [7].

The online implementation that will run parallel to the blended ones is using similar methods and it follows the ideas described in [3]. The presence of the teacher is not so intense. It is mainly commenting students' answers to the tasks they perform. Course structure will include short video clips of theory and examples. The assessment will be based on the similar weekly exams and measurement assignments as in the blended implementations. The course is more general than the blended ones, because students may enroll from any branch of engineering. The online course will also be offered in Finnish national portal of open UAS education.

As written above, some pieces of the model have been tried and reported before. Now it's just a time to wrap the package together. The basics and the idea of the new model have been presented to the students beforehand. So far, before the first real implementations the response has been supporting. The students have presented clever questions about the model, for example "If a student starts in online implementation, is it possible to move to a blended implementation smoothly".

CONCLUSIONS

As the real implementation of the model is still to come, there are no success stories or warning examples available yet. The model has been developed in the team of physics and mathematics teachers in Tampere UAS. The stakeholders that have been with the team in the development process are students of different educational programs of engineering and the

educational planners responsible for curriculum development of engineering in Tampere UAS. So far, the response has been promising. Especially engineering students have seen the model in very positive way and helpful.

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AN APPLIED EXAMINATION FORMAT FOR MEASUREMENT TECHNOLOGIES

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A written exam in measurement technologies usually includes problems for operational amplifier circuits, error propagation, signal analysis and analog to digital conversion. During corona, teaching changed from presence lectures to remote lectures and examination formats changed, too. Instead of a written exam, student project exams were proposed. The projects included a computer aided temperature measurement with operational amplifier circuits, a calibration procedure, error propagation and a written report. The student project exams were successful and the students' feedback was so positive that the student project exams are going to be continued.

Keywords: measurement technology, examination.

INTRODUCTION

Curricula in bachelor programs of mechatronics and mechanical engineering include subjects from major disciplines, from mechanical, from electrical engineering and from information technology which lead to a fundamental technical education including physics. Interdisciplinary subjects like measurement technology have to interconnect these fundamental disciplines for a deeper understanding of modern mechatronic systems.

Regarding measurement technology, students of mechatronic and mechanical engineering programs may not have in-depth preparation courses in electrical engineering and information technology to the same extent like students in electrical engineering and information technology, because they also spend time on mechanical engineering like statics, mechanics of materials, machine elements and kinetics in their first semesters. Nevertheless, engineers have to design and evaluate different sensor technologies and measurement technologies to apply them in system design and control technology for automation solutions and robotics.

During the lecture of measurement technology, aspects of a measurement chain are introduced. The students learn about the difference between accuracy and resolution. They gain skills in the selection and use of active and passive sensors, and the design of a corresponding measuring chain with operational amplifier circuits. During the labs, students apply themselves in the use of digital multimeters and digital oscilloscopes and in the implementation of computer-aided measurement recording.

According to the curriculum, students shall have the following subject-specific knowledge after the course: the physical principles of action of important sensors for physical quantities and their transfer functions, including optical sensors for distance and angle measurements, sensors for mechanical loads and for temperature measurements, amplification and filtering of electrical signals using operational amplifiers, description of continuous-time signals, analog to digital conversion and computer-aided measurement acquisition, error propagation and the use of statistics with normal distributions for measurement inaccuracies [1].

Traditionally, the examination used to be a written exam. All of the different subjects give great exam problems ranging from physics regarding sensors, from electrical engineering for

measuring bridges and operational amplifiers, mathematical problems including statistics with normal distributions and Fourier series for signal processing and filter design. During corona, teaching changed in 2020 from presence lectures to remote lectures and examination formats changed, too. Instead of a written exam, student project exams were proposed.

The first project was a computer measurement of the gravitation constant with the mobile phone software Phyphox [2, 3] of the RWTH Aachen and a written report in 2020. In a second project, students created a more sophisticated setup for a computer-aided temperature measurement and calibrated the measuring device during their exams in 2021. For these exam projects, the students pick up the required material at the university. During the corona semesters, we send the material to the students' home addresses by post.

In both cases, the examination requires the submittal of a report documents with a maximum of 20 pages and a demonstration video. These two electronic documents may be submitted either in the Learning Campus, the Learning Management System of the university or by email with attachments or with a link to students' dropbox. In the case of email, the examiner confirms the receipt of the email. For the second year, the issued components, the Arduino Uno, the prototype board, the PT100 temperature sensor, three resistors, and six cables had to be also returned.

Group work with two people is generally possible. The individual text passages have to be assigned to the respective authors in order to enable an independent assessment. Alternatively, group work with two persons is accepted if the group accepts a group grade. The evaluation criteria of the report are published to the students as shown in Table 1. The points refer to scope (i.e., an appropriate scope) and the content (i.e., a correct and meaningful content).

Table 1. Evaluation criteria for the report.

Criteria	Points
Form of the report (table of contents, list of references, introduction and summary)	2
Theoretical recap of the experiment	2
General description of the experiments	2
Description of the actual experiments and methods for the evaluation of the temperature function	3
Evaluation, modification of the measurement program, error calculation	3
Summary, Description of the results	2
Sum:	14

TASK DESCRIPTION FOR THE USE OF MOBILE PHONE SENSORS

The students shall determine the acceleration of gravity by a cord pendulum with two methods. In the method, the students shall use different thread lengths and directly determine the frequency of the oscillation with the Phyphox app. The measurements shall be repeated to minimize errors. A second method for determining the gravitational acceleration is to be carried out by exporting the measurement data to a CSV file, by importing the data to MATLAB and by using the Fourier transformation. Again, repeated measurements shall minimize errors.

As the Phyphox App and MATLAB and the resources are very instructive, the software preparation threshold has been comparably low and no further instruction had to be given. The students have participated in two online question-and-answer sessions so that no question remained open regarding the task description and evaluation scheme.

TASK DESCRIPTION AND GUIDELINES FOR THE ARDUINO UNO SHIELD

The students shall create a naive temperature measurement setup in Fig. 1 on an Arduino Prototype Shield. Secondly, the students shall measure the temperature-dependent voltage and, if necessary, an offset using the Arduino Uno and MATLAB. A third step includes a calibration of the measurement setup using boiling water (assuming T=100°C) and ice water (assuming T=0°C). The students shall determine the temperature as a function of the measured voltage and create an automated measurement program that outputs the temperature instead of the voltage.

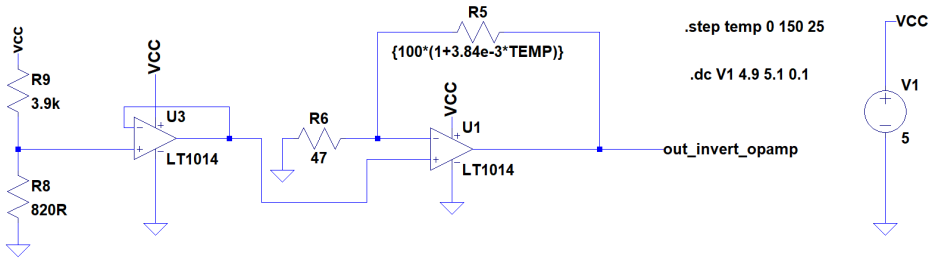

Fig.1. Circuit diagram example.

As a support, the students receive the links to start measuring analog voltage using the Arduino and MATLAB. Students have to install MATLAB which is available as a campus license and the "MATLAB Support Package for Arduino Hardware" as an add-on in MATLAB (see Fig. 2) [4].

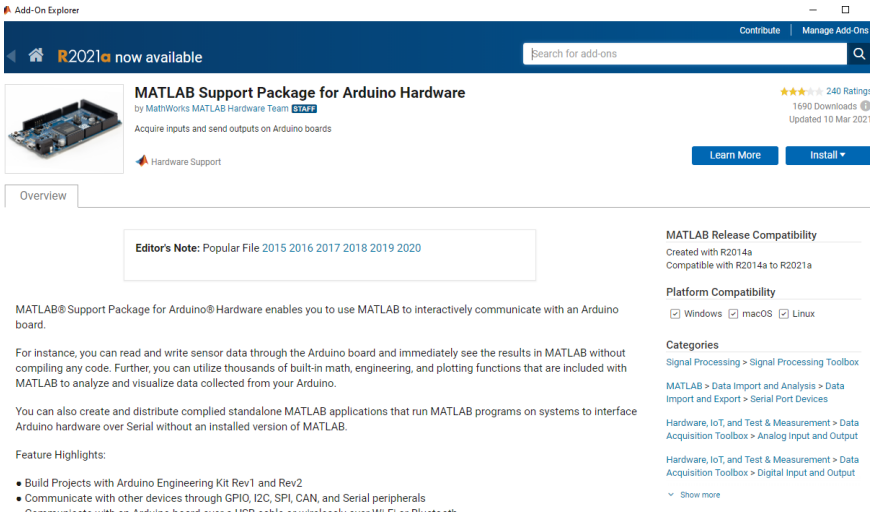

Fig.2. Screenshot of the "MATLAB Support Package for Arduino Hardware" installation.

After installation, the students have to check the connection to the Arduino which has to be established and tested, for example via USB (see Fig. 4 and 5). This guideline is important because the automated measurement is a prerequisite of the exam. In the right of Fig. 4, the value "COM6" is shown in the "Choose Port" field. This value is usually a different port on different computers, of course. Also, the use of USB hubs is discouraged, because it did not work for the authors.

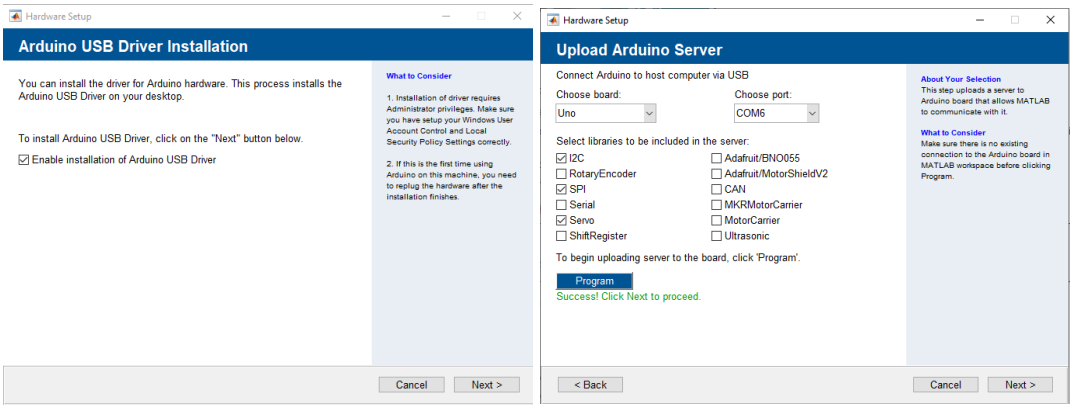

Fig.4. Screenshots of the menu navigation “Arduino USB driver”

For verification of the successful Arduino connection to the computer and for troubleshooting, the students also received the screenshots in Fig. 5. If the COM port is not displayed in the right of Fig. 4, the installation process is stuck. This is often related to a missing driver or when the driver is not installed. Whether the driver is installed or not, can be checked in Windows in the device manager (see Fig. 5 on the right). If the driver is not installed and if the Arduino board is not recognized, the driver has to be reinstalled. The link in [5] has been supplied to the students and has successfully worked for the authors.

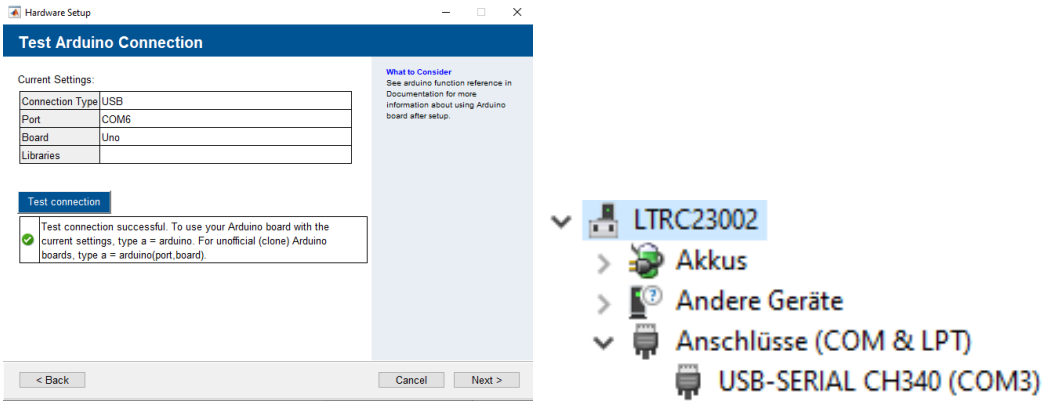

Fig.5. Screenshots of the successful test of the Arduino connection.

As a final piece of verification, the students receive a MATLAB m-file to read in the analog measured values from the analog inputs A0 and A1. The simple test case for easy reproduction is shown in Fig. 6. The analog terminals A0 and A1 are connected to two supply voltages of the board. The output by MATLAB on the screen appears with 5 V and approximately 3.2 V, respectively.

There is an operational amplifier LM324 on the Prototype Shield photographed in the right photo of Fig. 6. The data sheet can be found on the Texas Instruments website [6] or through a direct link [7]. On the prototype board itself, the connections are connected to each other per the columns. Again, two online question-and-answer sessions have been offered after the distribution of hardware and software so that no question remained open regarding the setup and regarding the measurement task.

```
%Arduino-experiment template
%S. Kipfelsberger, M. Versen

%ADC0 for "GND" für PT100
%ADC1 Vout PT100

Clear all;
a = arduino();
RawOffset = readVoltage(a, 'A0')
RawVoltage = readVoltage(a, 'A1')
Voltage=RawVoltage-RawOffset
```

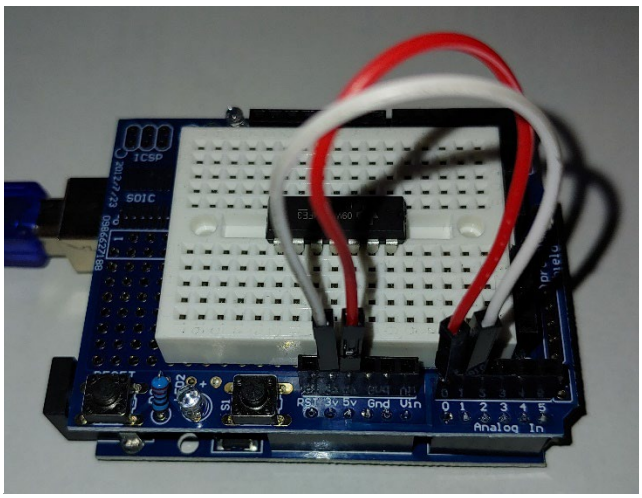

Fig. 6. Sample m-code and photo of the Arduino Uno board with Prototype Shield for successful testing of the m-file.

SOLUTIONS AND EVALUATION

As there was no examination risk during the corona semesters, a high number of students participated in the exams, i.e. in total 70 students of mechatronics and plastic engineering for the mobile phone project in the 2020 and 41 students for Arduino project in the 2021, respectively.

All registered students submitted their reports and returned their equipment for the Arduino project. By this, all students passed the exam, because they earned enough points according to the evaluation scheme shown in Tab. 1. In average, the students earned better marks in these two years compared to the average of the written exams in the previous years. The average was 1.6 and 1.5 for the years 2020 and 2021, respectively. I.e. more than 50% of the students submitted comprehensive reports and had marks with 1.3 or better.

As the students had full transparency about the evaluation criteria, they could skip any section of the report if they had written enough in the other sections. In 2020, nearly all students collected all points for the report format, e.g. the citation of references, for the descriptive sections for the theoretical background, for the experimental setup and for the actual experiments including the evaluation by the Fourier transform. In 2020, many students simply skipped the error propagation.

In contrast in 2021, most students collected all points for the report format and had detailed descriptions of the actual experiments, the calibration procedure and the development of the temperature measurement function. These students skipped parts of the more descriptive sections of the theoretical and experimental setup description and again the error propagation. On the other hand, nearly 72 % of the students realized the non-linearity problem of the evaluated temperature measurement scheme and discussed the problem properly. Some students even solved the problem with an alternative temperature sensor and implemented a more sophisticated calibration which was not part of the original project.

Interestingly, some students discussed their individual learning success in the summary section at the end of reports. The students rated the concepts as simple with high uncertainties while they also stated that the basic concepts of the lecture “measurement technologies” have been applied and thus practically repeated.

CONCLUSIONS

The positive examination results and more important the very positive self-evaluation of the students and the self-paced learning results encouraged the author to propose the student project exams in the new examination regulations of the TH Rosenheim starting in 2022 because the discussed exams were part of the exam exceptions of the Corona years. Actually, students requested this kind of exam in the following semesters, too.

The exam concept has been successfully extended to digital technologies and to microcomputer technologies exams for students in mechatronics and electrical engineering and information technologies.

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THE LECTURE OF THE FUTURE: IS FLEXIBILITY IN TERMS OF TIME AND SPACE AT THE EXPENSE OF LEARNING SUCCESS?

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A “hybrid” team-based physics course was developed and rolled out at the Albstadt-Sigmaringen University, Germany, with the intention to provide more flexibility in space and time for the students. Data on the correlation between type of participation and learning success showed, that participation in person together with the performance in other STEM related courses are the main predictors for learning success. Interestingly, it had no influence on the learning success of the non-participating students whether they participated remotely or not at all. Thus, the biggest challenge for the lecture of the future, which offers more flexibility in space and time, is the "activation" of students who participate remotely.

Keywords: hybrid lecture, flexibility, learning success

INTRODUCTION

The need to offer distance learning to prevent contagion during the pandemic years 2020 to 2023, sometimes even for students in different time zones, has accelerated the development of teaching methods that allow for flexibility in space and time. After the contact restrictions have been lifted, the request of a majority of students for more flexibility in space and time remained [1, 2]. Traditional classroom teaching, while allowing remote participation by video and audio conference systems, is a widespread approach to enable flexibility in space. Flexibility in time can be further promoted by integrating asynchronous “online” elements into the course syllabus while reducing synchronous teaching. Such “hybrid” course formats, combining “in person” synchronous and asynchronous “online” elements, have been successfully developed, see for example the AP50 Physics course by Eric Mazur [3].

Since remote participation at the Albstadt-Sigmaringen University, Germany has been available to students on a larger scale, two things have been observed. First, the proportion of remote students is rather high (often > 50%) and second, many instructors have the impression that remote students learn less. In other words, the assumption arises, that more flexibility in space and time by remote teaching is on the expense of learning success. This is in contrast to studies during the pandemic, which suggest, that remote teaching works as good as “in person” classroom teaching [4, 5]. However, the conclusions from these studies cannot simply be transferred to the time after the pandemic. During the pandemic, students found themselves in an extraordinary and new situation, while in the post-pandemic period, remote participation might be seen as a decision of convenience. As the student’s request for more flexibility in space and time will most probably remain, the search for the best format of the lecture of the future has just begun.

This study tries to add a piece to the puzzle by pointing the spotlight at the correlation between remote participation and learning success of a “hybrid” introductory physics course at the Albstadt-Sigmaringen University. The following section describes the course syllabus in more detail.

COURSE SYLLABUS

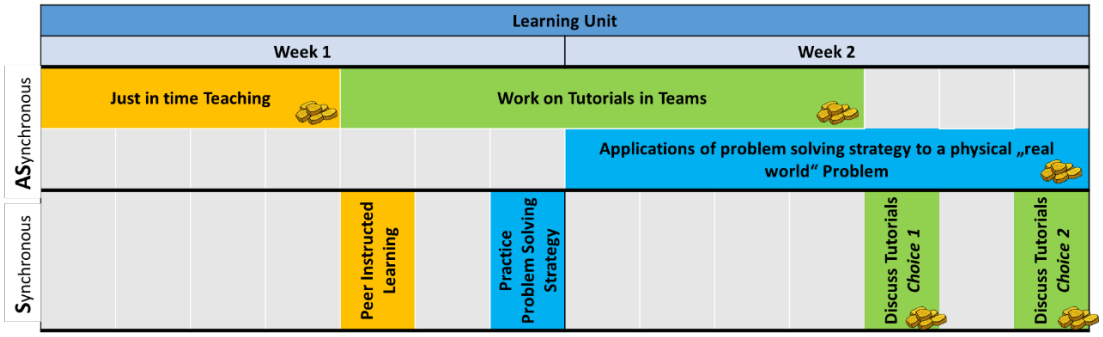

Fig. 1. Typical schedule of a bi-weekly learning unit assigned to a specific topic. The students collect points (indicated by the nuggets) by continuous efforts (CE) throughout the semester

In the fall semester 2022, a “hybrid” introductory physics course that encourages “active” learning [6] was developed and rolled out at the Albstadt-Sigmaringen University [7]. This team-based course comprises of asynchronous self-paced learning units and synchronous instructor guided sections organized in a repeating bi-weekly learning unit. Two synchronous units of 90 minutes were offered every week.

For the asynchronous learning units, the “Just-in-time Teaching” (JiTT) approach has been adapted [8]: The students familiarize themselves with the basic key ideas of a specific unit, e.g. fluid statics, by reading textbook chapters and watching introductory videos. Then, the students are asked to complete a small quiz and submit questions of conceptual understanding to the instructor to reveal misconceptions. Following this, the students work on specific physical tutorials [9] in teams and solve a “real word” physical problem by application of the strategy published by Burkholder at al. [10]. Both have to be submitted electronically and are evaluated by the instructor.

The format of the synchronous sections alternates weekly: One week, the revealed misconception from the asynchronous JiTT unit are discussed using “peer-instruction” [11] and students practice strategies for solving “real word” physical problems. During the synchronous section, the students in the classroom work together in teams of four on group tables. The remote students are also asked to work in teams using a digital whiteboard, which is mirrored in real time to the instructor’s computer. Ideally, the instructor moves from team to team to support the learning process, no matter if the team participates remotely or sits in the classroom.

The next week, the instructor discusses the previously submitted answers to specific physical tutorials with each team *individually face-to-face*. The student have the choice of participation at the discussion either remotely via video transmission or in person in the classroom. It is important to mention, that participation at the “tutorials” discussion is mandatory, in contrast to the non-mandatory participation at the “problem solving” section.

Fig. 1 summarizes a typical bi-weekly learning unit assigned to a specific topic, e.g. “Energy and Systems”. In each unit, the students collect points (indicated by the nuggets in Fig. 1) by continuous efforts (CE) throughout the semester in the asynchronous and partly also in the synchronous sections), which summed up to half of the final grade. Points (nuggets) were awarded for the results of the JiTT quizzes, submission of an understanding questions, the meaningful application of the problem solving strategy, and the group discussions of the tutorials. The other half of the grade was made up of a short final exam at the end of the semester addressing conceptual understanding and problem solving skills.

RESULTS AND DISCUSSION

Pseudonymized data on the type of participation, whether in person, remote or no participation was collected for each synchronous teaching unit throughout the fall semester 2023/2024. Key numbers of type of participation are shown in table 1 and Fig. 2.

Table 1. Key numbers of type of participation.

Key number	Description
p	proportion of "in person" participation in the number of enrolled students
r	proportion of "remote" participation in the number of enrolled students
n	proportion of "no participation" in the number of enrolled students
p/(p+r)	proportion of "in person" participation in the total number of participating students (excluding the not participating students)
r/(n+r)	proportion of "remote" participation in the number of "not in person" participation

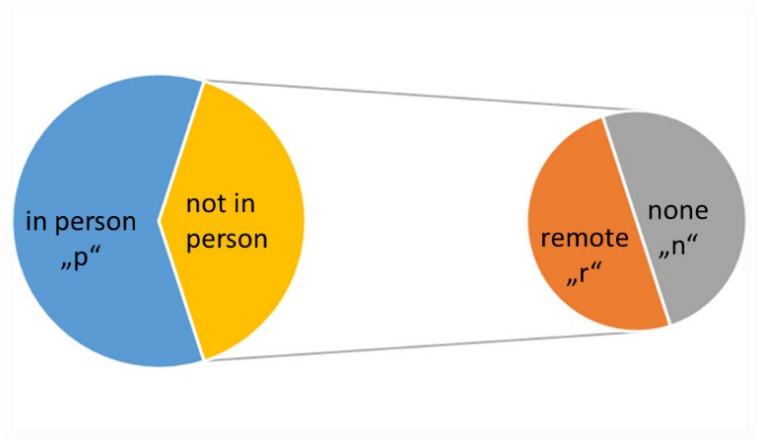

Fig. 2. Key numbers of type of participation. Example of a synchronous unit: 10 students enrolled, 6 participate in person, 2 remote, and 2 do not participate in a unit. p=0.6, r=0.2, n=0.2, p/(p+r)=0.75, r/(r+n)=0.5.

The key numbers of type of participation for the synchronous units are shown in Fig. 3 as a function of progressing timeline (number of unit) during the fall semester 2023/2024. The data of units 6 and 7 was partially lost. Six of the 22 units were only available by remote participation (p = 0) due to organizational reasons. Interestingly, there is no clear trend with progressing timeline for either of the key numbers, excluding the "remote teaching only" units.

Table 2. Key numbers averaged over all synchronous units and students (excl. "only remote" units)

Key number	Average	Standard deviation
p	0.3674	0.1155
r	0.2879	0.0903
n	0.3398	0.0715
p/(p+r)	0.5592	0.1458
r/(n+r)	0.4539	0.0982

The key numbers averaged over all synchronous units, excluding the "remote only" units, are shown in table 2. Looking only at students who decided to attend a particular lecture, in

average around 56 % prefer to participate in person rather than remotely. As the course was advertised as being optimized for more flexibility in space and time, i.e. in particular for remote participation, this number is remarkably high. This finding indicates, that most students found face-to-face in person discussion more beneficial to their learning success than remote participation, even if it was face-to-face by video.

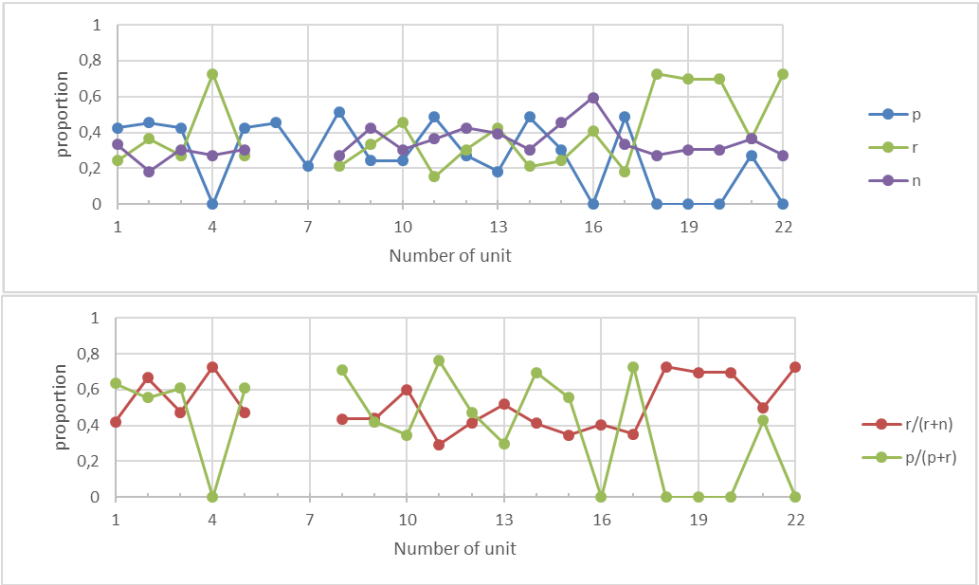

Fig. 3. Type of participation per synchronous unit vs. timeline of the semester. $n = 33$ students were enrolled in the course.

The non-participating students (around 34%) can be mainly assigned to two groups: students, who decided early in the semester not to participate at all but are still enrolled, and students, who already had participated in the previous semester but failed in the final exam (data not shown here).

The aim of this study was to analyze correlations between the type of participation and learning success in a team-based course that encourages "active" learning and offers flexibility in time and space. Learning success was defined as the percentage of points of the final exam and the percentage of points that were collected by continuous efforts throughout the semester. The exam and the continuous effort each contribute 50% to the learning success score, which totals 1 for the full score. In addition, the learning success was also measured by a conceptual pre- post-test with average gain after Hake [12] of 39.94% . However, these results were not analyzed further, as the overlap between the participants in the pre- and post-test was too small. However, the competencies required to achieve full learning success include half conceptual understanding and half problem-solving skills.

Fig. 4 shows the average success of the students in the course (success in final exam (EX) and continuous efforts (CE)) as a function of the proportion of participation “in person” (ps) averaged over all synchronous units. The average success was determined as the average proportion of correct answers. The low p-value of the t-test ($p < 0.05$) and the correlation coefficient after Pearson ($\hat{r}_{Pearson} > 0.75$) indicates, that there is a strong linear correlation between participation in person and success at a significance level of 5%.

At a first glance, this might lead to the easy conclusion that participation in person is better for learning success than remote participation.

However, correlation does not mean necessarily causality. Therefore, another key factor should not be overlooked in the discussion: the students' averaged previous performance in all other courses related to science, technology, engineering and mathematics (STEM). Fig. 5 shows the average success of the students in the course (success in final exam (EX) and continuous efforts (CE)) now as a function of their previous STEM performance. These results call into question the hasty conclusion that the type of participation is the only driving factor for learning success.

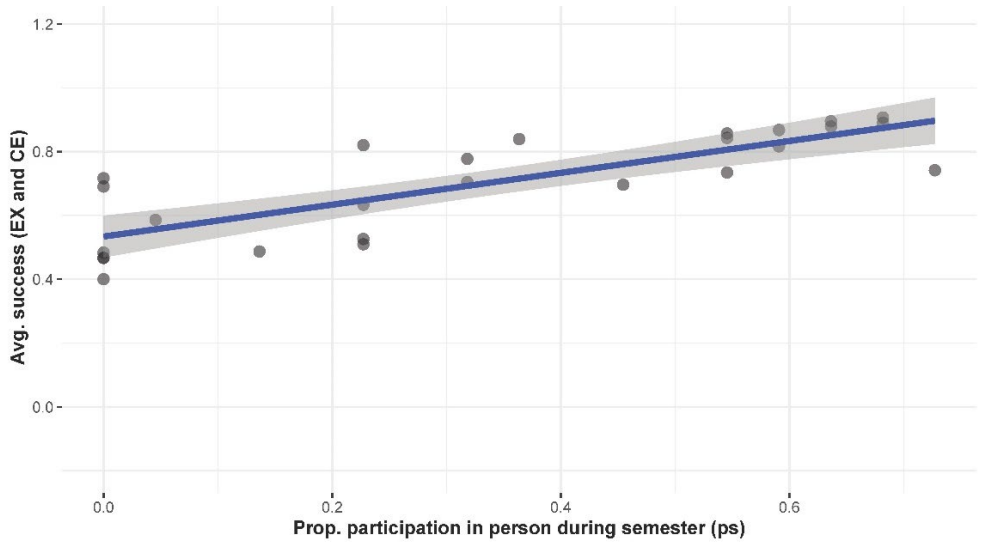

Fig. 4. Average success of students as a function of proportion of in person participation during the whole semester. $n = 26$, $p\text{-}Value = 7.32 \cdot 10^{-7}$, $\hat{r}_{Pearson} = 0.80$

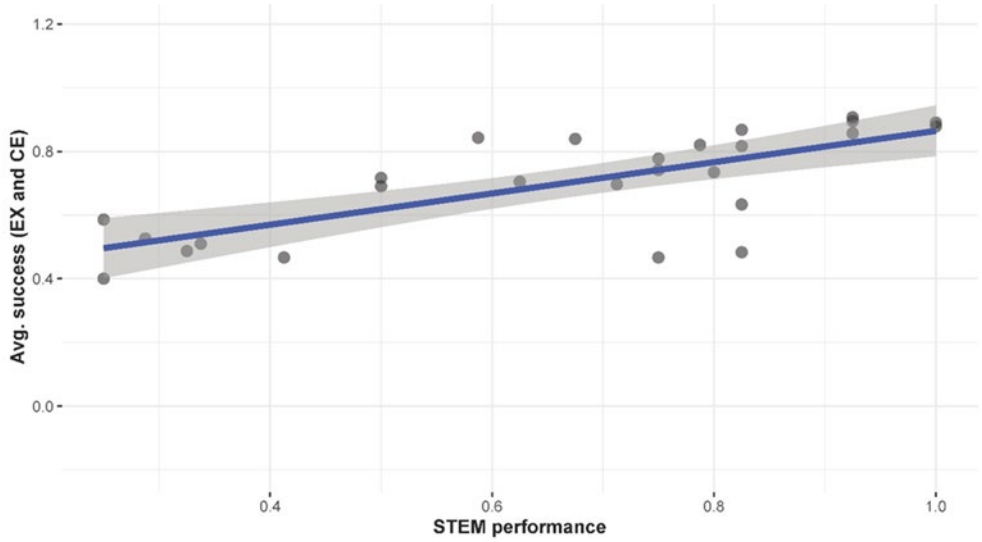

Fig. 5. Average success of students as a function of average STEM performance. $n = 26$, $p = 2.85 \cdot 10^{-5}$, $\hat{r}_{Pearson} = 0.72$.

To gain deeper understanding of the dependence of average learning success on the two variables ps and $STEM$, a multiple linear model has been fitted to the data and the results are shown in Table 3. Obviously ps and $STEM$ are linear correlated to the average success on a significance level of 5%, as seen by the low p-value of the significance test ($p < 0.05$).

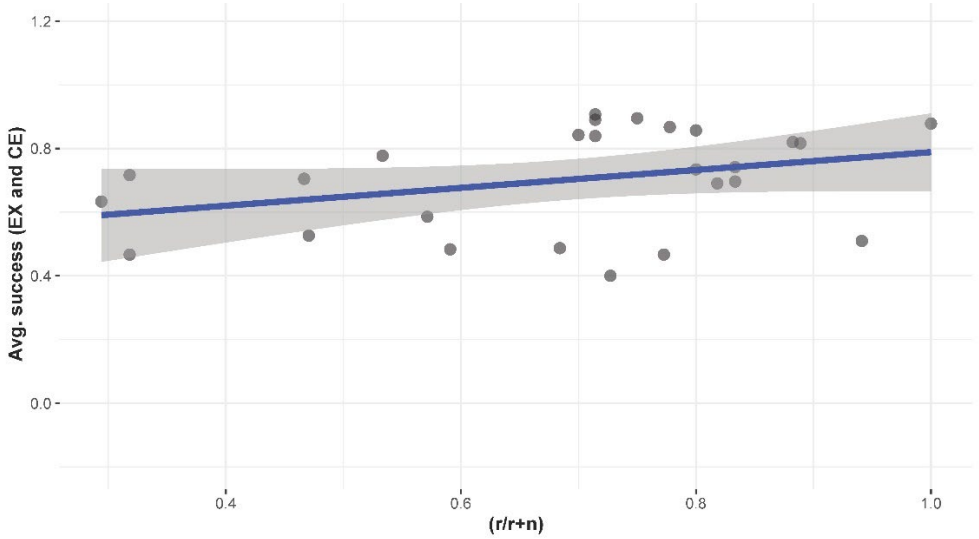

Fig. 6. Average success of students as a function of the proportion of remote participation in the number of "not in-person" participation. $n = 26,\ p = 0.1, \hat{r}_{Pearson} = 0.33$

The estimates indicate that the proportion of in-person participation during the semester explains more of the average success than the STEM performance. Thus, participation in person is a good predictor for average success, while STEM performance is still a significant but less important predictor.

Table 3. Multiple linear model. Residual standard error: 0.09156 on 23 degrees of freedom. Multiple R-squared: $R^2 = 0.7054$ ($R = 0.8399$).

	Estimate	Std. error	p-value
Intercept	0.43114	0.05652	9.62e-08
ps	0.358976	0.09591	0.00103
STEM	0.22351	0.10481	0.04386

If the type of participation is a good predictor for learning success, why is that? Since it is well known, that "active" learning promotes learning success [6], it is consequent to look at the activity level during remote participation. Typically cameras were switched off in the synchronous problem solving units and the active contribution of remote students to discussions or group work was rather low (typically < 50%), although digital whiteboards and speakers were available to enable active participation. This leads inevitably to the question, if "remote" students do participate at all or maybe simply screen-record the synchronous session and do something else. For this reason, the proportion of remote participation in the number of "not in-person" participation $\mathrm{r}/(\mathrm{r}+\mathrm{n})$ is another interesting key number. If this number has no impact on average success, there would be no difference between "no participation" or "remote participation".

Actually, as shown in Fig. 6, the data show no significant linear or other correlation. Surprisingly, if students are not participating in person, it seems to be irrelevant for their success, whether they participate remotely or not at all. This suggests that online participation in the synchronous sections is associated with a very low level of activity, which is known to decrease learning success [6]. In short: more remote participation means less activity and less learning success. It is assumed that the level of activity also in the asynchronous sections correlates with learning success; however, there is no reliable data to support this hypothesis.

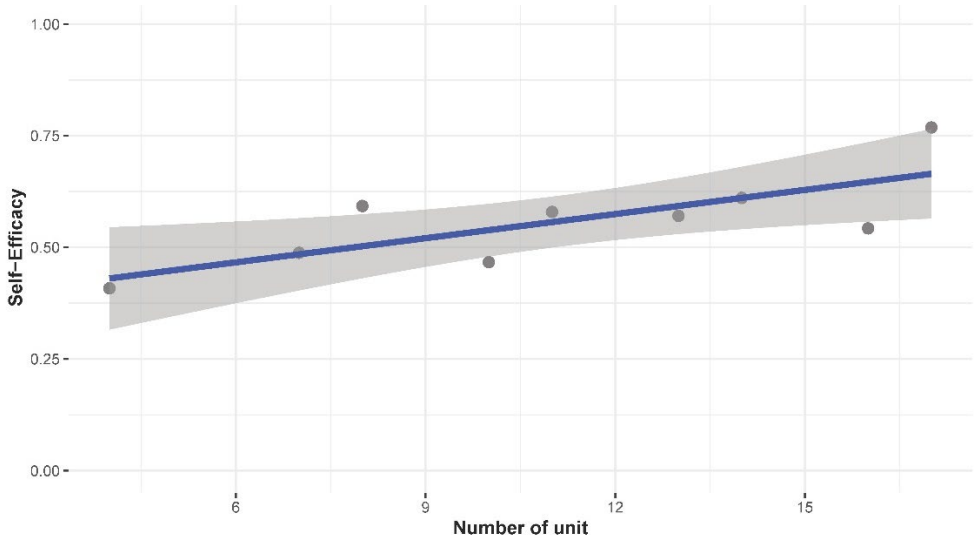

Fig. 7. Key number of self-efficacy SE vs. timeline of the semester (number of unit). $n = 9$, $p = 0.02$, $\hat{r}_{Pearson} = 0.76$.

Finally, the student's self-efficacy was measured for most problems and tutorials they had to solve during the semester. The Students were asked to estimate their own performance on a 4 level scale from 0 to 100% and to state how confident they were about their self-evaluation on a 5 level Likert-scale. The product of these two numbers normalized to a maximum of 1 was defined as the key number SE for self-efficacy. Fig. 7 shows the development of self-efficacy as a function of progressing timeline (number of unit) during the semester. Obviously, the self-efficacy increases linearly with progressing timeline of the semester, in the hope to improve also learning success.

CONCLUSIONS

This study analyzed the impact of several key parameters of participation, whether remote, in-person or not at all, on learning outcomes in an introductory physics course at Albstadt-Sigmaringen University, Germany. The team-based physics course was designed to offer more flexibility in terms of time and space by introducing asynchronous and synchronous elements that encourage active learning. Learning success was measured by the percentage of points of the final exam and multiple continuous efforts throughout the semester addressing conceptual understanding and problem solving skills. It was observed, that around 56% of the students that participated prefer to come in person rather than participating remotely. This number is remarkably high, as the course was advertised as being optimized for more flexibility in space and time, i.e. in particular for remote participation. Obviously most students found face-to-face in person discussion more beneficial to their learning success than remote participation, even if it was face-to-face by video. The data also revealed that students' self-efficacy increases significantly as the semester progresses, which hopefully promotes learning success.

Moreover, it was found that the average learning success correlates linearly with two variables on a significance level of 5%: the overall proportion of in person participation, and the performance in other STEM related courses. However, the proportion of in person participation shows a more significant correlation to learning success and explains most of the

learning success in the actual course, while performance in other STEM related courses is a another significant predictor for learning success but with less impact.

The current data also support the conclusion that remote participation does not lead to any different learning success than “not participating at all”. This suggests that students participating remotely are most likely not "actively" engaging in learning, or in other words, remote participation encourages passivity, which is known to reduce learning success.

In the ideal lecture of the future, the learning success should not depend on the type of participation, whether in person or remotely. Unfortunately, this goal has not yet been achieved by the current course design. Based on this study, the biggest challenge is the improvement of activation of remotely participating students. Rachbauer et al. [13] published key strategies to increase activity level of remote participating students. This includes, for example, using digital boards instead of physical boards and setting up digital break rooms for group work. In the current course, these strategies were put into practice together with the possibility of remote participation in quizzes via smartphone. However, the success of these strategies was not as great as hoped for. Therefore, as a next step, two further elements will be implemented into the current course to increase the activity of remote participants: Installing break-out rooms that are assigned to the fixed teams and connected to a partner in the classroom, as well as permanent video transmission of the classroom. In addition, the author hopes for a fruitful discussion during the PTEE conference in 2024.

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