Challenges in Physics Education

Claudio Fazio
Paul Logman *Editors*

Physics Education Today

Innovative Methodologies, Tools and Evaluation

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Challenges in Physics Education

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Challenges in Physics Education addresses professionals, teachers, researchers, instructors and curriculum developers alike, with the aim of improving physics teaching and learning, and thereby the overall standing of physics in society.

Proposals for publication should be submitted to Marina Forlizzi (marina.forlizzi@springer.com) or to daniele.bignami@fondazione.it.

Claudio Fazio · Paul Logman
Editors

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Introduction

Innovation in education has become increasingly important in recent years in many disciplines. Physics is not an exception in that: investigating innovative ideas for physics instruction has been a widely observed and pursued research field for many years, as teachers and researchers look for effective ways to improve teaching methods and enhance student learning outcomes.

One of the most encouraging developments in physics education is the embrace of active learning strategies. In place of simply lecturing to students, teachers and researchers have seen that involving students in hands-on and minds-on activities, as well as group conversations, can result in greater comprehension and appropriation of physics concepts. This approach allows students to take an active role in their learning, rather than simply absorbing information passively.

Innovations in physics education can also be explored by the use of real-world applications and problem-based learning, to engage students and connect physics concepts to practical, everyday situations and mathematical modeling. By giving students the chance to put their knowledge to use in solving real-world problems, teachers can show them the importance of physics in their lives.

Finally, research in physics education is itself a major innovation. By studying how students learn physics and recognizing effective teaching approaches, researchers can contribute to the development of new methods of physics education. This research can be used to inform the development of curricula, teacher training initiatives, and educational policy decisions, with the aim of enhancing physics learning opportunities for students at all stages.

In conclusion, it is important to innovate in physics education in order to keep up with the ever-changing landscape of physics and to ensure students are well-equipped to handle the challenges of the future. By embracing new teaching methods, technologies, and research, educators can inspire a new generation of physicists and help students develop the skills and knowledge they need to succeed in the 21st century.

The main focus of this book is to present research papers about innovation in physics education from both research and applicative points of view. The 13 papers of the book are selected, by means of double-blind peer-review by at least 2 reviewers per paper, from the 64 papers submitted to the III World Conference on Physics Education, held online in Hanoi, Vietnam, from December 13 to 16, 2021, and discuss results of genuine research works dealing with Physics Education. The topics that the selected 13 papers address are:

- University Physics: research and good practices
- Secondary school physics
- Interplay between physics and mathematics
- Contemporary physics and modern physics in schools and universities
- Evaluation and assessment of student learning and development
- Initial teacher education, teacher professional development, and Technological Pedagogical Content Knowledge
- Competence-based Physics education

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Selected Keynote

Lessons Learned and Unlearned: A Lifelong Journey with 'Active Learning' as a Constant Companion

Alexander P. Mazzolini

Abstract My lifelong journey from post-graduate student to retired physics professor has been very rewarding, especially with active learning as my constant companion. This paper discusses key milestones in progressing from a 'sage on the stage' to a 'guide on the side'. The journey from 'teacher-centered' traditional lecturing to 'student-centered' active learning involved a very long and winding path, with several missteps along the way. To successfully navigate such a path required a clear bearing and a good compass. In my case the 'bearing' was the conviction that active learning was an effective way of teaching, and the 'compass' was physics education research, which I used to guide me in determining the efficacy (or otherwise) of my active learning interventions. Active learning is an education philosophy that is best shared, with students and with other teachers. As a member of UNESCO's Asian Physics Education Network (ASPEN), I was able, along with colleagues, to introduce active learning to many physics teachers throughout Asia via hands-on, minds-on, active learning workshops. With the assistance of UNESCO, I helped to develop a 5-day, full-immersion, teacher-training program for academics and high school teachers. The program was called 'Active Learning in Optics and Photonics' (ALOP). The ALOP teaching guides were originally written in English, but have been translated into French, Spanish, Arabic, and several other languages. Between 2004 and 2019, there have been 35 ALOP workshops in the developing countries of Asia, Africa, Central and South America, and Eastern Europe. Workshop examples are presented in this paper.

Keywords Active learning · Physics education · Student-centered learning

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1 The First Few Steps on the Active Learning Journey

Throughout my academic life, I have been very fortunate to have travelled on a wonderful journey with 'active learning' as my constant companion. To successfully navigate such a complex journey requires a 'clear bearing' and a 'good compass'. My bearing has been the strong conviction that active learning is a very effective teaching strategy, and my compass has been physics education research, which I have always used to gauge if my teaching interventions have been moving me along in the right direction. Like most academics of my era, I was taught via traditional, passive, transmissive teaching methods. While I thrived in this environment, many of today's students do not. Because of the way I was taught, and because I always assumed that I was a 'good' teacher, there have been many lessons that I have had to learn, and some that I have had to unlearn, during my active learning journey.

In this paper, I would like to acknowledge my sincere gratitude to the International Commission on Physics Education (ICPE) for awarding me (along with my friend and colleague, Pratibha Jolly) the 2019 medal for Physics Education, which recognizes "*outstanding contributions to physics teaching of a kind that transcends national boundaries*". I also would like to thank Manju Sharma for nominating me for the award, and Scott Daniel for encouraging me to agree to the nomination. I sincerely hope that this paper can be a positive influence on young physics academics, who are considering how they can best assist their students on their own learning journey.

In 1981, as a young PhD student, I had my very first experience at lecturing. I taught a large, first-year physics lecture group for several weeks at Melbourne University, while my supervisor was overseas at a conference. A few years later, near the end of my PhD, I also taught a complete third-year physics course in electronics. Those two opportunities convinced me that I wanted to become a university academic. I loved preparing and presenting my lectures (using logic, well-reasoned arguments, enthusiasm, and showmanship). In 1986, my dream became a reality, and I gratefully accepted a tenured academic position at Swinburne University of Technology, in Melbourne, Australia. To help bring my lectures alive, I used physics demonstrations to excite and motivate my students– in fact my office was full of demonstration equipment, and I used wheeled suitcases to take my demonstrations to lectures. I won a grant to develop a set of 'Physics in a Suitcase' portable lecture demonstration kits, and these were used by academics for their introductory physics classes at Swinburne, and in high school physics outreach activities in Melbourne and in regional areas of my state of Victoria [1].

My lectures were popular, and students loved my lecture demonstrations. The student questionnaires from the University's 'end of semester' course evaluations were usually very positive. My lectures were very teacher-centered, but that was exactly how I liked them! I loved being the 'sage on the stage' who could usually put on a great performance. Unfortunately, my lecture demonstrations were not linked to any real learning strategy– they were there to fascinate the students, and to make my lectures more interesting. Looking back now, I would say that many of my demonstrations were too clever, too complex, and too 'teacher-centered'. Students were being entertained but I now think that my demonstrations did not improve their understanding of physics concepts.

In the years around 1995, I attended several different physics education workshops in Melbourne (at Monash University). I believe that they all were sponsored by the USA's National Science Foundation (NSF). Although my recollections are hazy, I think the workshops may have been facilitated by several of the early 'leading lights' in physics education research including Alan van Heuvelen, Fred Goldberg, Lillian McDermott, Jim Minstrell, and perhaps others. These US education experts introduced me to the concepts of 'active learning', 'student engagement', and the need to confront 'student misconceptions' during the learning process. By showing physics education research data, they were able to question the effectiveness of traditional passive lecturing, which at that time was the cornerstone of my teaching. The research-based evidence suggested that being a 'guide on the side' was a more effective teaching strategy than being a 'sage on the stage'. Furthermore, I started to understand the importance of quantitatively measuring the effectiveness of any teaching intervention, via a rigorous education research process.

I remember that at one of these NSF workshops, I spoke to a volunteer high school student about 'rolling a ball off the edge of a table'. This student was highly motivated, intelligent, and thoughtful, and had volunteered to help the workshop organizers during his school holidays. I spoke to the student about the forces acting on the ball after it had rolled off the table. I asked the student to draw (on a whiteboard) the forces acting on the ball. He drew an arrow pointing downward. I then asked him if he was sure. He thought for a moment, then drew an additional arrow along the direction of motion of the ball (see Fig. 1). This was my first 'face-to-face' experience with a student's physics misconception. It was an example of the common Aristotelian misconception that 'all motion requires a force'.

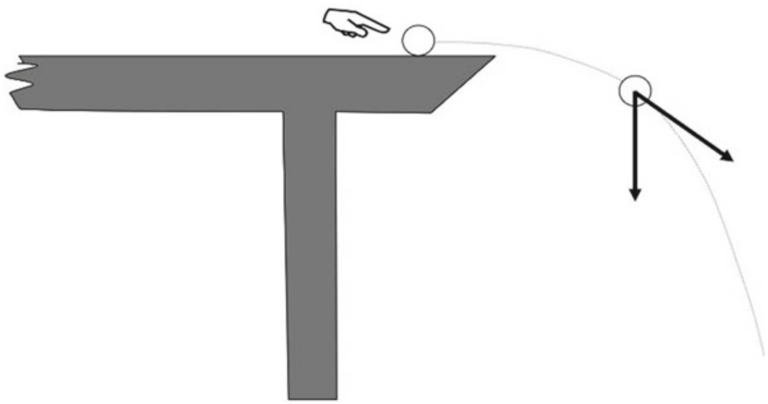

Fig. 1 Student's misconception of forces. The student was asked to draw the forces acting on the ball once it has left the table. The student correctly drew an arrow pointing vertically, then drew an additional (incorrect) arrow along the direction of motion

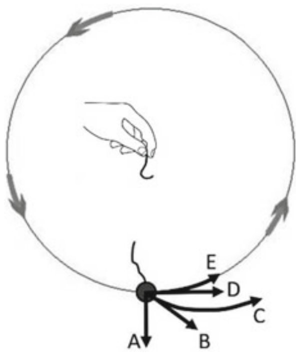

Fig. 2 Possible student predictions for the path of the ball after the string has broken

In the NSF workshops, I had discovered that active learning could be used to help student identify, confront, and correct deep misconceptions in physics. I wanted to adapt my lecture demonstrations so that they could address the misconceptions of my own students. For example, one *common misconception* about circular motion can be stated as follows–

> When a ball on a string rotates horizontally in a circular path, there is a force (centrifugal force) that acts radially outwards on the ball, keeping the string tight. The tension in the string is balanced by this centrifugal force

In my class, I would explain the demonstration that I was about to perform for the students– that I would swing a ball on a string in a horizontal circular path. I would then ask the students to predict what the path of the ball would be after I released the string (or if the string broke). As shown in Fig. 2, the students would predict whether the path would be–

(A) along a straight line radially outwards,
(B) along a straight line at 45° to the radial direction,
(C) along a spiral line outward,
(D) along a straight path tangential to the radial direction, or
(E) along the same circular line as before the string broke.

I would perform the demonstration (with the aid of an overhead video camera), and then the students (and I) would discuss any differences between their predictions and the observation (i.e., path D).

2 Introducing Active Learning to the Asian Physics Education Network, and to My Own University

During the late 1980s, I started to be involved with international education activities. One of the groups that attracted my attention was the UNESCO-funded Asian Physics Education Network (ASPEN), which had been established in 1981. In the early 1990s,

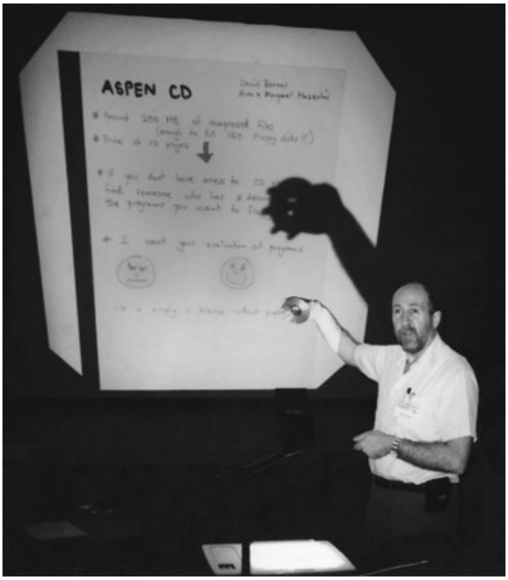

Fig. 3 Introducing the 'ASPEN CD' at the ASPEN conference on Modern and Innovative Technologies for Asian Physics Education (MITAPE), which was held in Manila in 1996

I became the Australian representative for ASPEN. Figure 3 shows a photo of an ASPEN conference in the Philippines in 1996. UNESCO had recently funded the 'ASPEN CD' project, which enabled me to produce 500 copies of a data CD with 200 MB of freeware (e-textbooks and computer programs) for physics education. In those days, the internet was essentially non-existent in most of the developing countries of Asia, so the ASPEN CD enabled many Asian educators to easily access a large range of electronic teaching resources. I was able to widely distribute the free CD at several ASPEN conferences and meetings.

I became ASPEN's Executive Secretary in 1997, and in 2008, I was honored to be elected ASPEN's Chair (or President). In the late 1990s, the UNESCO representative for Asia (Minella Alarcon) and I wanted to introduce active learning to ASPEN. In 1999, I had the opportunity to organize an international physics workshop on active learning at Swinburne University. The workshop was again funded by the US National Science Foundation and was called 'Promoting Active Learning in Introductory Physics Courses'. The workshop presenters were Priscilla Laws, David Sokoloff, and Ron Thornton– all internationally-recognized experts in active learning. UNESCO was very supportive and provided funding for ASPEN representatives from nine countries to participate in the workshop. Minella was also able to attend.

The active learning workshop by David, Priscilla, and Ron showed me (and the other ASPEN participants) that–

1. Active learning was a more effective teaching strategy than traditional passive learning.
2. Interactive Lecture Demonstrations (ILDs), which used a specific 'learning cycle' called 'Predict, Observe, Discuss and Synthesize' (PODS), were effective in

correcting student misconceptions, and that ILDs could be effective even in very large classes, as long as the PODS learning cycle was used.

3. ILDs could generate quantitative data (by tracking objects in real time via sensors interfaced to a computer, or digitized video clips). The quantitative data could then be used by students to interpret their observations more clearly.

I learned that the PODS learning cycle was critical to the successful implementation of ILDs. The PODS cycle consisted of eight steps–

1. The facilitator *explains* the demonstration that is to be shown to the class.
2. Students *individually predict* what they think will be the outcome of the demonstration.
3. The facilitator *summarizes* the various predictions of the students.
4. Students then *discuss* their prediction in small groups with other students who have different predictions.
5. Students can then *revise* their original predictions.
6. The facilitator then performs the demonstration, and the students *observe* the results.
7. The facilitator and the students then *discuss any differences* between predictions and observations.
8. The facilitator sums up and then discusses with the students how the observation *fits* into their understanding of physics.

Over the next decade, UNESCO funded many ASPEN active learning physics workshops throughout Southeast Asia (see, for example, [2]). David Sokoloff was often part of our workshop team, and ASPEN benefited greatly from his expertise. I recall that, on several occasions, team members (including myself) would revert to our old 'passive teaching' habits during enthusiastic discussions with workshop participants. During debriefing meetings, the other team members would gently remind the 'sage on the stage' that they were "*lecturing too much*" and that they should refocus again on being an active learning facilitator. With our ASPEN active learning journey, there were always opportunities to relearn important lessons!

During this period, I also started using active learning in several of my courses at Swinburne University. I taught a large introductory electronics course, and I would use a mix of traditional lectures and ILDs to teach topics that students found particularly difficult, for example, operational amplifiers (op amps) [3]. In the latter years, my then PhD student, Scott Daniel, worked with me to develop some ILDs for other topics in electronics (for example, resonance [4] and phasors [5]).

Many students found the op amp ILDs very helpful. One student comment from an early focus-group interview transcript stated

> that *"with our lecturer, he…actually set up an experiment to show us how it works and there was a sheet to fill in our predicted answer, like what we think it's going to look like, and then we conduct the experiment and get the actual answer and … compare it … so you kind of know where you went wrong."*

The PODS learning cycle required students to make predictions and observations of the various active learning experimental measurements in our ILDs. We developed prediction sheets (which students would hand in) and observation sheets (which students would keep) for our ILDs. We used the students' prediction sheets together with focus groups, questionnaires, and surveys to gather data for our education research. Later, we also used electronic polling devices (clickers) to automate some of our data collection. Using the results of our research, Scott and I were able to upgrade our op amp ILDs over a period of several years [6].

Again, there were many lessons to be learned in this part of our active learning journey. Our student feedback told us that our original ILD 'op amp demonstration board' was far too complex and did not fully match the diagrams on the prediction sheets, so the board was redesigned to make it much simpler and clearer, and the worksheets were updated so the diagrams closely resembled the new board. Figure 4 shows the old op amp demonstration board, which looks quite complex, even when we covered some of the knobs with black tape. Figure 5 shows the new op amp board, which was much simpler and looked very similar to the diagrams in the prediction and observation sheets. Scott and I taught the ILDs as a team, so we could share the workload and give each other instant feedback on our ILD facilitating.

For our op amp classes during this time, we normally had about eight hours of traditional lectures followed by about two hours of ILDs. The active learning intervention was quite successful–

- In 2013, students who attended the op amp ILD sessions as well as the traditional lectures showed a significant improvement over those who had attended only the traditional lectures. The results as determined from a diagnostic test showed an improvement from 26 to 42%.
- In 2011, when we did *not* run op amp ILDs, we found that the average exam score for the op amp question was very low (27%) compared to the average exam score for all other questions (which was 55%). Clearly the students struggled with op amps that year.

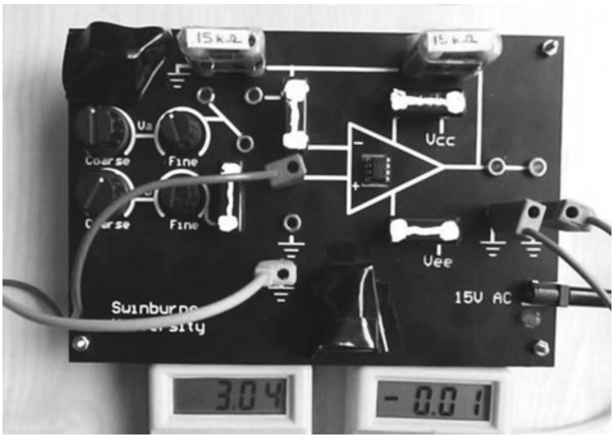

Fig. 4 Old complex op amp circuit board

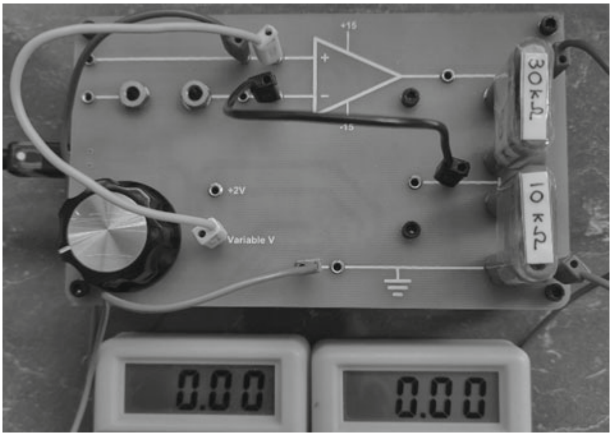

Fig. 5 New, simpler op amp circuit board

- In 2012 and 2013, when we did run op amp ILDs, we found that the average exam score for the op amp question (58%) was comparable to the average exam score for the other questions (64%.). This showed that the op amp ILDs were having a positive impact on examination scores.
- In 2012, students were surveyed for their perceptions about how effective, helpful, and interesting op amp ILDs were, compared to traditional lectures. A high percentage of the students (79%) gave a positive response.

As we progressed with our active learning classes, Scott and I learned many more lessons–

- We learned that active learning interventions should be monitored (videoed or observed) to ensure that facilitators did not revert to bad habits (and by that, I mean traditional lecturing). On too many occasions, monitoring of my teaching showed that I was doing too much lecturing and not enough facilitating.
- We also realized that lesson plans should *always* use a learning cycle that is consistent with active learning.
- Using the 8-step PODS learning cycle, we found that the peer discussion between students with different individual predictions was particularly useful. Figure 6 shows an example where the percentage of students who predicted the correct observation for an op amp ILD experimental measurement increased from 29 to 81% after a short (2 min) discussion with their peers.

In around 2010, I established the Engineering and Science Education Research group (ESER) at my university, to support staff who wanted to consider using active learning in their classes. ESER created a ‘community of practice’ so our physics and engineering educators could share their experiences about active learning and use education research to test the effectiveness of their teaching interventions. This

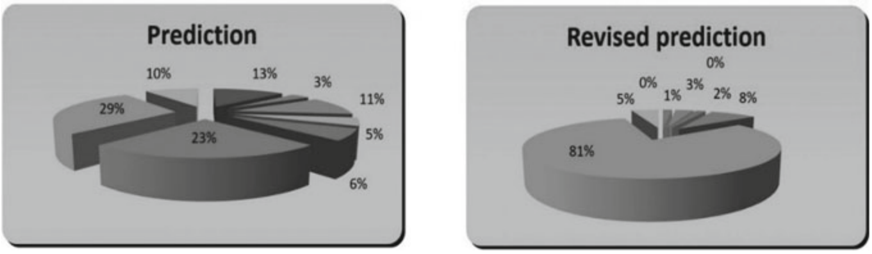

Fig. 6 Students' initial (left) and revised (right) predictions after a short peer discussion. The percentage of students with the correct prediction increased from 29 to 81%

was a critically important step and allowed many educators at the university to identify limitations in their traditional teaching methods. For example, here is a reflection from a popular and well-respected physics academic at Swinburne University who is discussing the importance of education research for improving his teaching effectiveness.

> *"Prior to the existence of ESER, I was quite dismissive of measuring the effects of my teaching practice … [as I believed] it would straightforwardly confirm my thoughts that I was a good teacher. However, I am now very convinced of the exact opposite; that these investigations are indeed quite complex, and their outcomes are anything but trivial."*

And another reflection from a physics research-intensive professor after receiving instant student feedback while using audience polling devices (clickers) with his class. "*You think you've done a great job teaching them, then 60% answer 'don't know' to a question!*" Timely feedback like this helped motivate academics to consider change in their teaching strategies. In the engineering and science faculty at Swinburne University, we used commercial audience polling devices, but some of my ASPEN colleagues often used more 'low-tech' methods (colored pieces of paper) to obtain instant student feedback (see Fig. 7). Nowadays inexpensive 'audience polling systems' are usually linked to the students' mobile phones.

3 Developing an Active Learning Strategy for Developing Countries Throughout the World

The development of a UNESCO international active learning program focused on one specific physics topic allowed me, and a small group of my colleagues, to introduce active learning to many developing countries throughout the world.

By 2003, Minella had moved to UNESCO's Paris office. She wanted to develop a physics-oriented active learning workshop program specifically designed for developing countries. The program would focus on the topic of optics, and in November 2003, a working group met at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, to discuss the general outline of the program. The working group

Fig. 7 Participants at an Asian active learning workshop using a ‘low-tech’ method (colored pieces of paper) to obtain instant student feedback

members were—Minella Alarcon from UNESCO, Gallieno Denardo from ICTP, Eugene Arthurs from SPIE (Society of Photo-Optical Instrumentation Engineers), Zohra Ben Lakhdar from Tunisia, Vengu Lakshminarayanan from the USA, Ivan Culaba & Joel Maquiling from the Philippines, and myself from Australia (and also representing ASPEN). The newly conceived program was called ‘Active Learning in Optics and Photonics’ (ALOP), and its aim was to train physics educators from developing countries in both optics and active learning.

In May of the following year, David Sokoloff and I met with Minella at UNESCO’s Paris headquarters**,** and together we sketched out the various workshop topics and activities for the proposed ALOP program. A few months later, a larger group of us met in Manila, the Philippines, to further discuss the ALOP plan and test the initial concepts of the program.

ALOP is an intensive, 5-day, hands-on, minds-on, workshop, for training high school physics teachers and university academics [7]. Initially the workshop program consisted of six teaching modules, but in recent years the last two modules have been merged so that five modules exist today–

1. Introduction to Geometric Optics
2. Lenses and Optics of the Eye
3. Interference and Diffraction
4. Atmospheric Optics
5. Optical Data Communication

The last module was developed by me and uses active learning to explore aspects of modern optical data communications, via activities that are based around a set of relatively simple circuits (for example, LED and laser transmitters, phototransistor receivers). The module also introduces the concept of sending different information streams simultaneously along a single optical fibre (using different colors for each information stream). Essentially, this last module was a capstone unit, showing quite modern advances in optical communication that required an understanding of the physics principles developed in the other four modules.

In November 2004, the first ALOP was held in Cape Coast, Ghana, and it was a great success. ALOP was designed to empower teachers from developing countries to–

1. *refresh* their skills in optics and photonics,
2. *experience* a student-centred teaching method (in this case active learning),
3. *learn* about physics education research that demonstrated the effectiveness of active learning, and
4. *use* low-cost and locally available teaching materials, so that teachers could try active learning with their own students.

The ALOP program also developed an extensive 250-page user manual (with both student and teacher guides) [8]. The ALOP manual was originally published in English, but has now been translated into French, Spanish, Arabic, and many other languages. The manual has now been updated in a second edition.

Figure 8 shows various members of the ALOP family, at an ALOP planning meeting in Manila (in 2010). You can see the original members (Minella, Zohra, Vengu, David, Ivan, Joel, and myself), and some more recent members—Joe Niemela (representing ICTP) who was the ALOP secretary, and later became the ALOP director when Minella retired, and Souad Lahmar (from Tunisia), who was my assistant at one of the early ALOP workshops. She is a great physicist and educator, and she soon earned her place as an expert facilitator in the ALOP family.

Between 2004 and 2019, there have been 35 ALOP workshops throughout the developing countries of Asia, Africa, Central and South America, and Eastern Europe. Figure 9 shows some of the participants in ALOP Indonesia (2019) working with one of the facilitators (David). Figure 10 shows part of 10 complete sets of optics kits that are distributed at no charge to ALOP participant groups after the end of each workshop. These kits are very simple and can be easily and inexpensively reproduced locally. The ALOP workshops and kits are all funded by UNESCO, ICTP, SPIE and local funding organizations.

But even with the ALOP active learning journey, I still had many lessons to learn. The original optical communications kits that I developed were well-designed, reliable, and elegant. They were constructed on custom-built printed circuit boards, and one board even had an inexpensive microprocessor to control a Red–Green–Blue composite LED (called an RGB white LED) [9]. Apart from the 10 sets of kits handed out after each workshop, in general, teachers did not have access to the printed circuit boards and microcontroller that they needed for the optical communications module. Feedback from teachers showed that while they enjoyed the optical communication activities, they could not easily share these activities with their students.

So, I completely redesigned the kits, using very simple components that most teachers could access (either from eBay or local electronic markets). For example, Fig. 11 shows the phototransistor receiver circuit used in the optical communications module—(a) the original phototransistor receiver (with its custom-built

Fig. 8 The ALOP facilitator team. Back row from left– Minella Alarcon (ALOP Director), Souad Lahmar, Zohra Ben Lakhdar, Vengu Lakshminarayanan, Joe Niemela (ALOP Secretary), and Alex Mazzolini. Front row from left– Joel Maquiling, Ivan Culaba, and David Sokoloff

Fig. 9 ALOP Indonesia 2019

printed circuit board), and (b) the redesigned phototransistor receiver (without any custom-built components).

Figure 12 shows the circuit that controls the RGB white LED in the optical communications module– (a) the original RGB white LED controller (with its custom-built printed circuit board and custom-programed microprocessor), and (b) the redesigned

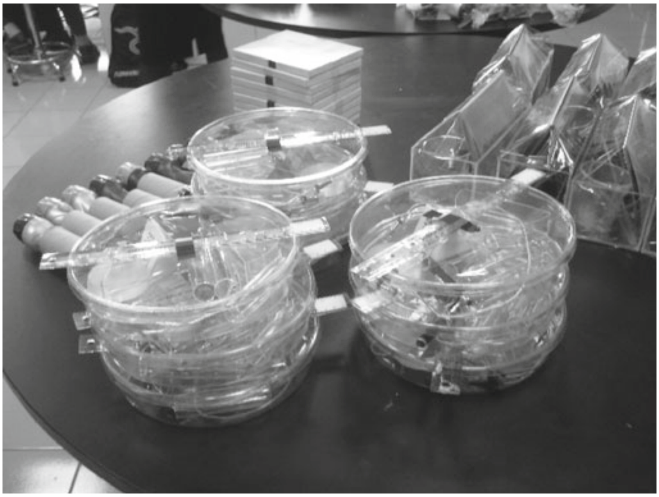

Fig. 10 ALOP equipment kits before distribution

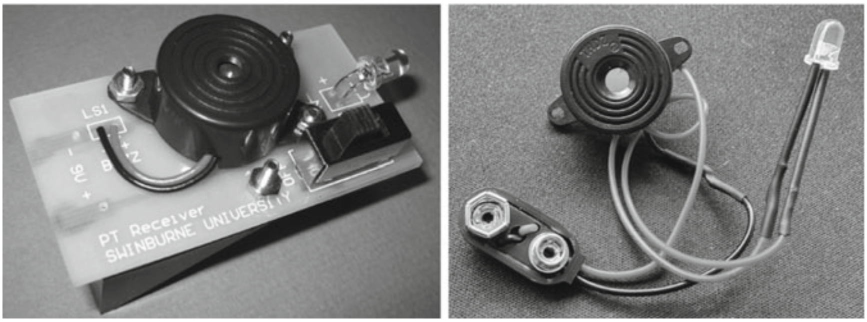

Fig. 11 **a** Original phototransistor receiver. **b** Redesigned phototransistor receiver

RGB white LED controller (which uses three simple mechanical switches to operate the LED).

Understandably, there have not been any ALOP workshops during the COVID19 pandemic. Nevertheless, David and I have continued to disseminate the ALOP philosophy by facilitating online, virtual, ALOP 'mini workshops' at conferences. The virtual ALOP workshop presented at the third World Conference on Physics Education (WCPE3) consisted of two, 90-min sessions that showed examples from the ALOP modules and allowed participants to experience a 'distanced' version of active learning for themselves.

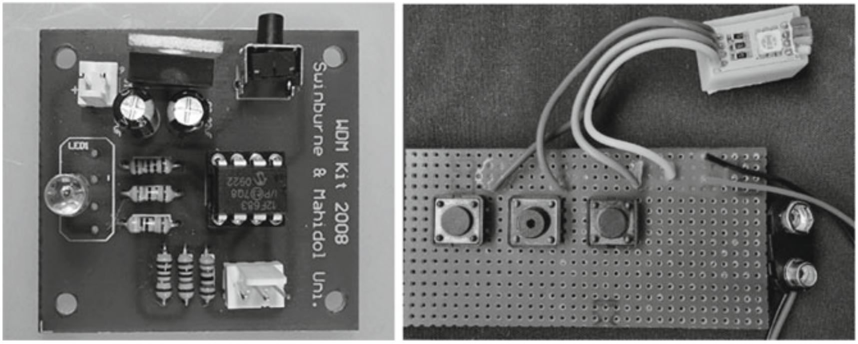

Fig. 12 **a** Original RGB LED controller. **b** Redesigned simple LED controller

4 Conclusion

My lifelong journey with active learning has been fulfilling and rewarding. As an educator, it has been a great privilege to have had the opportunity to influence ‘how students learn’ and ‘how teachers teach’. My active learning journey has had occasional obstacles along the path, for example–

- some physics and engineering students needed to be persuaded that they had to be actively engaged in their own learning, rather than just passively sitting back, and listening to what their teacher told them,
- some workshops in developing countries needed a lot of creative problem-solving when serious technical or equipment issues occurred ‘in real time’, and
- some physics and engineering academics did not see why active learning was necessary [10]. These educators needed to be convinced that confronting students’ misconceptions about simple physics concepts was necessary, even if these concepts had already been taught in a traditional learning setting.

But the obstacles in my active learning journey were made less challenging by many of my colleagues who helped me along the way. Overcoming these obstacles required patience, conviction, respect, the results of education research, and good humor.

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Selected Symposia

Supporting Educational Transitions in Physics

Eilish McLoughlin, Tandeep Kaur, Jan De Lange, Mojca Čepič, Dagmara Sokolowska, and Paul Grimes

Abstract Educational transitions present opportunities and challenges for students and teachers. Between the ages of 10 and 16 years old, students undertake several transitions in their school lives—including transitions across school systems (e.g., primary level to second level), transitions between teachers, transitions across subjects (e.g., moving from a general science curriculum to a specialised physics curriculum). This paper discusses the approach adopted in the Supporting Transitions Across Mathematics and Physics Education (STAMPEd) project to support teacher professional learning and enhance student learning in physics across educational transitions (STAMPEd Project (2021–2023). Supporting Transitions Across Mathematics and Physics Education ERASMUS+, KA2 [1]). A systematic review revealed that the experiences of transition, if negative, may impact not only on students' academic achievement but also strongly associate with the development of their scientific identities and their aspirations for scientific careers. The project

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adopted an Educational Design Research (EDR) approach to monitor and evaluate its impact on participants (educators, teachers, and learners) over a three-year duration. This paper will discuss the initial design principles and key elements of a professional learning programme adopted to support teachers in addressing transition issues in physics from primary to second level. Two examples of rich tasks that have been designed to support student learning in physics across educational transitions in physics are presented.

Keywords Transitions · Physics education · Rich tasks

1 Introduction

The low uptake of physics is an issue of significant concern internationally, with trends showing decreasing participation at upper second level and scientific careers [2]. This issue has been attributed to students' negative attitudes and their perceived utility of school science [3–5]. It has been noted that a decline in students' interest and attitudes towards science occurs as they progress to secondary education [6, 7] With the transition from primary to second level education, students experience a myriad of changes in many aspects of their social, emotional and intellectual environments such as, adjusting to new school environments [8], change in teaching practices [9], self-doubt, friendship worries and experiences of bullying [10, 11], and difficult psychological and social experiences [11, 12]. The experiences of transition, if negative, may impact students' interest and motivation for learning science and they can develop negative attitudes towards science [6, 13]. The negative attitudes developed during this transition strongly associate with their future aspirations to study science and can impede the development of their scientific identities [3, 14].

Studies have reported a significant dip in students' academic achievement and progression in science learning across the transition from primary to secondary education [15–17]. Moreover, negative transition experiences also impact on students' psychological well-being and can affect their self- esteem and self-concept [7, 14]. According to the most recent findings of the Trends in International Mathematics and Science Study (TIMSS) 2019, the percentage of eighth graders who were less positive and confident about learning science was twice that of fourth graders who reported so. Furthermore, eighth grade students showed more negative attitudes to earning Physics and Chemistry compared to Biology and Earth sciences [18]. These studies highlight the need for interventions to promote science interest in young students, especially the age group of 10–14 years, the age reported as a critical period for the formation of science aspirations of young children [3]. In addition, a comprehensive understanding of the factors that shape students' experiences of transition and the implications of these experiences is required.

This study reports on the approach adopted by the Supporting Transition in Science and Mathematics Project (STAMPEd) project to address transitions in physics between primary and secondary school [1]. The project partners from Ireland, Belgium, Poland and Slovenia, supported teachers to engage in professional learning to identify and address transition issues in Physics. An Educational Design Research (EDR) approach was adopted by the STAMPEd project to monitor and evaluate impact on its participants (educators, teachers, and learners) over a three-year period.

2 Educational Design Research

Educational Design Research (EDR), stemming from the 'family' of design research, addresses educational problems in real-world settings. It is a problem-oriented approach that focuses on reflection and cycles to achieve the most efficient solution [19]. EDR is the act of interacting systematically with the subject of study and taking the learnings from that to improve practice. EDR has two primary goals, developing knowledge and developing solutions. Like other research approaches, it aims to develop scientific knowledge, but it also strives to develop interventions in practice. EDR extends theoretical knowledge through data collection and analysis embedded in the cyclic development of a solution to the problem being tackled. The nature of these solutions can be educational products, programmes or policies. While there are several definitions and descriptions of EDR, there is common agreement on the essential aspects, and common features appear in both the descriptions of design research, design-based research, and educational design research. Plomp's description of EDR as "…the systematic study of designing, developing, and evaluating educational interventions as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them" succinctly describes the key ideas that most descriptions of EDR are based upon [20].

There is a widespread consensus that for teacher professional learning to be successful it needs to take place over an extended period; needs to be valued by teachers; and should focus on the learning needs of their students. The aim of the STAMPEd project is to support teachers and students that are working within and across educational transitions in physics. The project adopted a model of professional learning, as shown in Fig. 1, where teachers are facilitated to:

- co-design rich tasks in physics
- conduct Practitioner Inquiry (PI)
- collaborate as part of a Professional Learning Community (PLC).

3 The Initial Design Cycle: Literature Review

The initial stages of the EDR study involved a systematic review of existing literature on educational transitions. A qualitative review of research on transitions from primary to secondary school science published during the period

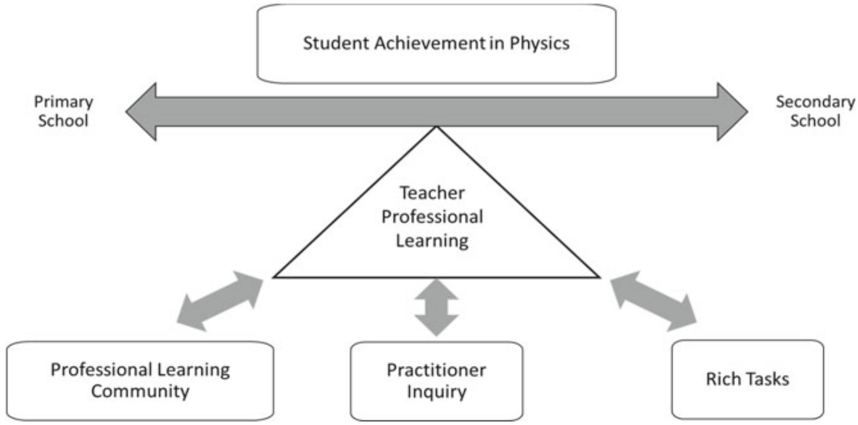

Fig. 1 STAMPEd approach to addressing transitions in physics from primary to secondary school

1990–2020 was conducted. The databases searched for the review were Academic Search Complete, Education research complete, British Education Index, Education Research Information Center (ERIC), and PsycINFO via EBSCOhost and Web of Science.

The criteria used to identify studies to be included in this review were: peer-reviewed publications in the English language that involved students aged 10–16 years. Studies focusing on specialized or vulnerable groups, or ethnic or racial groups were excluded from the selection as this review focused on normative transitions in science from primary to secondary school. The search process, followed by screening of titles, abstracts and full texts yielded 47 publications for inclusion. This formed the corpus of studies that were reviewed. The literature review centred on the following question:

> What factors influence students' experiences of science transition from primary to secondary school?

The review identified three broad categories of factors that influence students' experiences of science transition from primary to secondary school: (i) student self-regulation, (ii) school and academic related and (iii) social factors. A total of 28 studies were identified that report on the factors influencing students' experiences of science transition. Figure 2 provides an overview of the factors identified within these three categories.

The category of student self-regulation includes factors related to behaviours, beliefs and/or emotions that could influence an individual's experiences (positive or negative) in transitions. For example, emotions or feelings about self, school belongingness, motivation, and engagement. Many studies note that secondary school students develop negative attitudes towards science and feel less motivated to engage in science learning [15, 21]. This has been linked to the classroom practices employed in secondary school science classrooms. Primary school students enjoy science

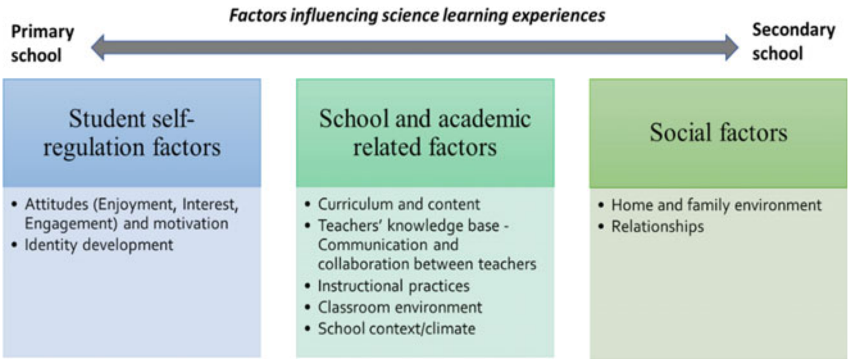

Fig. 2 Factors that influence students' experiences of science transition from primary to secondary school

classes more than secondary students because of greater use of hands-on activities and practical work in science teaching [22]. The preferences and interest for learning science is closely related to students' academic performance [15, 23]. A positive correlation between self-concept and science achievement has also been noted [24]. Positive beliefs of self-ability not only increase students' engagement in science but also contribute to the development of their scientific identities [25]. Additionally, Self-regulating factors such as the ability to adjust and stress management, good social and emotional adaptability skills also impact students' experiences of science learning across the transition [26]. Studies also reported gender differences in science self-efficacy and aspirations for the future, with higher science aspirations and self-efficacy amongst boys than girls [27].

The school and academic factors include aspects relating to curriculum and content, teachers' knowledge base, instructional practices, and school and classroom learning environment. Majority of the studies reviewed in this category explored the role of the classroom learning environment in developing students' attitudes towards science learning. These studies highlight a mismatch between student-expected and the actual learning environment in secondary science classrooms [28, 29]. This was attributed to students' perceived dissatisfaction with the traditional learning environment and lack of practical teaching approaches in secondary school science. Other studies on exploration of instructional practices employed in secondary science teaching noted lack of independent pupil investigations [30] and lesser use of manipulative skills for science instruction [31]. Findings from these studies highlight the important role of inquiry-based hands-on activities to enhance students' interest and engagement in science [21, 30, 32]. Exploration of students' acquisition of content knowledge for specific topics such as heat, matter or energy concepts reported a lack of conceptual understanding and a gap between general knowledge and scientific knowledge across transition [29, 33, 34]. Gender differences in perceptions of the learning environment have also been reported. For instance, while boys prioritized activities in secondary school, girls were more concerned about their relationships with friends and teachers [35].

Social factors relate to home and family environment and relationships. Only six studies reported on social factors. These studies investigated factors in relation to students' relationship with teachers, peers and their parents. Change in student–teacher relationship was the most difficult one for students when they moved to secondary school. Secondary school students felt a lack of personal interaction with their teachers and reported decreased motivation for learning [35, 36]. Thurston et al. [37] found relationships with peers to be very influential in promoting positive transition experiences [37]. Gender-based differences in terms of relationship concerns have also been highlighted, with girls reporting higher levels of dissatisfaction than boys [35, 36]. Furthermore, parents' attitudes towards school science also impact their children's science aspirations for the future [3]. Other factors related to home and family environments that influence children's science related beliefs and aspirations include quality of parenting, parents' education, their involvement in school activities, and the level of family income [16, 38].

The review identified three key factors that influence students' experiences of science learning across their transition from primary to secondary school—student self-regulation factors, school and academic related factors, and social factors. Findings suggest that students' experiences of science transition cannot be attributed to any single factor as various contextual factors may combine to shape these experiences. A significant impact of these combined factors is a shift in students' attitudes and motivation in science learning and a decline in academic performance in secondary school which echoes the findings from other reviews on general transition [12, 39]. More than half of the studies in this review presented evidence of a decrease in student motivation and engagement and an increase in negative attitudes towards science in secondary school students. Also, the majority of the studies report negative experiences of students, confirming similar findings from previous reviews on general transition from primary to secondary school [12, 40]. These negative experiences act as barriers to students' learning and result in disengagement and disinterest for science. Addressing these negative factors requires a greater focus on the continuity between the primary and secondary school science curricula and improved coherence in teaching and learning approaches at both levels. Future research should focus on examining the impact of increased consistency between pedagogical approaches used in primary and secondary school science. Establishing and supporting professional learning communities that bring together primary and secondary teachers could lead to increased collaboration and communication between teachers and enable sharing of best practices in science teaching. The review findings also highlight the influence of the classroom learning environment on students' self-regulation skills and their experiences of science learning across the transition. Therefore, positive learning environments that foster the development of students' self-esteem and confidence to support their learning across the transition must be promoted.

The review found relatively less research on the social factors. Interventions that focus on addressing social factors such as peer relationships, parental influences and student–teacher relationships are needed. These may include measures such as increased parental involvement in school activities and measures that provide greater emotional support to students. This review highlights the need for stronger collaboration between teachers and researchers to support student learning in physics across transitions.

4 Supporting Practitioner Inquiry

The next phase of the design study adopted the approach of the Erasmus+ 3DIPhE project to support teachers in carrying out a practitioner inquiry to address a transition issue in physics and mathematics [41]. Teachers are continuously faced with challenges about the impact of their teaching. However, finding out systematically what works in one's professional practice is generally not regarded as a part of the teaching job description [42]. Teachers must develop an inquiry stance at their level, about their teaching practice. Their inquiry is about their profession, their practice, their daily work with students and leads to a lot of learning for teachers and is known as 'practitioner inquiry'. Practitioner Inquiry (PI) is a form of professional learning defined as the systematic intentional study by teachers on their own practice [43]. The teachers (=practitioners) engage in systematic reflection and take action for change by asking questions ("wonderings"), gathering data to explore their wonderings, analysing the data, making evidence-informed changes in their practice, and sharing their learnings with others [44]. There are many variations on how to do a PI that can be found in literature, and these all tend to have recurring characteristics. PI is intentional: it is about improving the classroom practice. PI is part of the teachers' job! In many cases it is something they probably already do. PI is about collecting data, and this is crucial in making learning visible. Students must be involved during the practitioner inquiry. PI must be done systematically. Conducting a PI can be done on your own but there is a lot of evidence that impact on students' learning is greater if it is done collaboratively. Nancy Dana defines a professional learning community (PLC) as "a group of teaching professionals who meet regularly to learn from practice through structured dialogue and engage in continuous cycles of inquiry" [45].

5 Rich Tasks in Physics and Mathematics

It was also important in the STAMPEd project that students and teachers experience engaging tasks and activities that support their physics learning. Physics is an experimental science, and this should also be reflected in the learning and teaching of physics. Experiments in physics education have different roles. Demonstrations introduce phenomena and allow students to gain initial experience, e.g., sometimes they are used for illustration of relations among variables or demonstrations of cause and consequence relations. They are also the most common mode of experimenting during lectures with many students. A single set of equipment is needed, which means both, reduction of costs and time for preparation. But demonstrations may not be efficient. Even an active teacher, who discusses observations and actively communicates with students, can find that several students remain disinterested after observing a demonstration. Laboratory experiments provide scientific skills, that is, students learn to use measuring equipment during the structured, step by step defined labs.

Over the past few decades, several approaches have been promoted that involve the participation of students in experimenting. These approaches vary from simple, interesting and easily performed hands-on experiments to projects, where students pursue inquiries stimulated by their own interests, following their own ideas, designing their own experiments. One of those methods is a well-studied approach called Inquiry Based Learning (IBL). The IBL approach follows the steps characteristic for the scientific method. A problem or phenomenon is presented to students, a tentative explanation(s) for the features of the phenomenon is(are) formed, experiments that test the explanation are suggested, and based on the experimental results the tentative explanation is pursued or discarded. This process is supported by a teacher, who takes the role of a mentor/supervisor steering the students' work with questions and hints. Experiments are usually carried out in groups of students, therefore this approach also fosters collaborative work of students, sharing responsibility and supporting development of other soft skills important for teamwork.

The life of a student, while progressing from one lecture to another, from one grade to another, from one school to another, is very often not smooth. Problems that occur during certain steps in education, were called "transitions" in the ERASMUS+ project STAMPEd [1]. In this project, for supporting students to cope more effectively with transitions they meet in mathematics and physics education, activities that are based on IBL methodology were chosen as an example. If properly designed, such activities allow for establishing communication within groups of new students and with new teachers, when students are progressing from one level of education to another. Besides, the main goal of these activities is encouraging and supporting a learning process. Similarly, if properly designed, activities can help students to bridge the language gap between the professional language of physics and mathematics and everyday language. Well-designed activities can promote student conceptual understanding, increase their level of knowledge and enable transfer of knowledge to new problems. As teaching and learning activities developed in the STAMPEd have a plethora of aims and goals, they are described as "rich tasks".

A construction of a rich task is a research problem by itself. Not every IBL activity could be considered a rich task. Alternatively, could any IBL activity be transformed into a rich task? To answer such questions, the criteria for "rich tasks" have to be established. From a practical point of view, one can identify a "rich task in mathematics and/or physics" any task or activity, which—fosters learning of mathematics and physics concepts by active involvement of students in carrying them out and simultaneously—addresses at least one of the problems that occur because of various types of transitions. In this paper, the criterion for designing rich tasks is illustrated through two examples.

Example 1. The first example focusses on collaborative group work during a study of load capacity independence of the structure of a paper bridge. Participants are asked to construct a bridge from one A4 paper. In the next step the groups enter a competition, which group constructs "the best bridge". The property called "the quality" of the bridge calls for operationalization. One has to decide, what is the measure of this property, for example, a load capacity. The task is appropriate for introductory physics lectures as they very often focus on measurement. Besides regular measurement protocols for length, mass or time, this task introduces a new property, the load capacity of the bridge, and for searching the best structure, also the measuring procedure of the load capacity has to be determined and agreed upon. So, the activity also includes the introduction of measurement as a procedure that should be well determined to ensure the same results of different groups, is reliable and accurate. Next, the shape of the bridge profile heavily influences the capacity and groups have to find the best profile and establish the mode of comparing the load capacity. Students usually start from very similar folded profiles, try with several layers, study the number of folds etc. However, the best profile is not a folded paper, and to find the not so evident solution requires discussion, listening to each other and measuring of the load capacity requires also physical collaboration among members of the group. Students therefore get acquainted with the abilities of their peers in teamwork, and they get to know each other better. The teacher observes students' actions in group and if the class is new for her/him and gets a first impression on how students act, how original their ideas are, how they are able to defend their ideas etc. This activity has a strong social component and can be used effectively at the beginning of the school year, with a new teacher, new subject, new peers, to promote teamwork and collaboration. In addition, as shapes of bridge profiles are based on geometry considerations, links between physics, mathematics and engineering are established.

The bridge building activity has been tested with several groups of in-service teachers, pre-service teachers, and project partners. Different approaches were adopted by the groups. As the activity is very simple and straightforward, participants start to collaborate eagerly and are immediately involved in discussion. In addition, all groups considered what was a fair test/determination of the "quality". Therefore, the procedure for measuring the load capacity was quickly chosen as a measure for a quality of the bridge and participants always (easily and happily) agreed on a single but well determined procedure. However, few groups were able to design a bridge to support loads heavier than 1 kg, and all groups had to change the shape from initial folded paper to rolled paper—which seems the optimal solution.

Example 2. The second example provides a context to otherwise pure mathematical graphs. A graph of the same shape is given to students, but the axes are different and relate to different physics quantities for different groups of students. Groups have to develop a story that links dependence provided with a graph and an everyday story that could yield such graphical representation of certain measurements. The activity supports collaborative work, combines everyday language and technical language and establishes the context for graphical examples used in mathematics and physics.

The activity was tested with a group of 20 in-service teachers and with a group of 15 pre-service teachers. The stories developed were discussed from different points of view and include the use of everyday and technical language from physics and/or mathematics. While the teachers did not have many problems to "invent" a situation given by the graph, the pre-service teachers used almost exclusively everyday language to describe the situation, while most of the in-service teachers included the use of technical terminology to describe the phenomena shown in the graphs. This example clearly indicates the challenges in bridging every day and technical language used in school to describe phenomena.

6 Conclusions

This paper discusses the initial design principles and key elements of a professional learning programme adopted to support teachers in addressing transition issues in physics from primary to second level. The approach builds on a model of teacher professional learning that facilitates teachers to collaborate as part of a Professional Learning Community (PLC) to conduct a Practitioner Inquiry (PI) on their practice [46]. The ERASMUS+ STAMPEd project has supported teacher educators from Ireland, Belgium, Poland and Slovenia to collaborate online to design a professional learning programme to support teachers in addressing transition issues in physics and mathematics. An Educational Design Research (EDR) approach has been adopted to monitor and evaluate the project impact on participants (educators, teachers, and learners) over a three-year duration. A review of literature identified three key factors that influence students' experiences of science learning across their transition from primary to secondary school—student self-regulation factors, school and academic related factors, and social factors. Partners have collaborated to design rich tasks to address these factors and use them to support teacher professional learning. An active exchange between educators and teachers provided useful feedback for further improvement of these rich tasks. Further research is needed to examine teachers' experiences of designing and using rich tasks in their physics classroom and determining how they influence student learning in physics.

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Enhancing Mathematization in Physics Education by Digital Tools

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Abstract The GTG Mathematics in Physics Education follows the philosophy of supporting physics understanding by the conscious use of mathematical structures in physics teaching. We discuss the possible roles of digital tools in promoting physics understanding by fostering sense making of computational models, using geometrical visualizations or interpreting app-generated diagrams in a physics context. We look into three types of digital tools: (a) Smartphone apps that allow data collection from the phone's internal sensors to effortlessly produce graphical representations of the data. (b) GeoGebra, that combines different mathematical representations and allows their visualization and manipulation. (c) Computational modeling via Vpython where students can build or manipulate a computational model and compare it to experimental results. We will describe the potential of these tools to improve understanding of different mathematical features in physics, as well as obstacles that educators should take into account. In addition we present some empirical findings concerning graphs from smartphone apps and experiences from teacher professional development.

Keywords Digital tools · Mathematization

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1 Introduction

We live in a time when digitalization influences almost all areas of our lives and is also becoming increasingly relevant for students, school, and teaching. The diversity and multitude of possibilities to use and implement digital tools is overwhelming, allowing passive reception as well as active use and creative construction. In this contribution, we cover a range of possible tools, which we selected for their relevance to mathematization in physics lessons. The goal is to analyze which options digital media could offer in supporting mathematization in physics, focusing on modeling, sense making of the interplay between mathematical model and reality, and specifically the interpretation of app-generated diagrams. These aspects were chosen because digital media provide above all possibilities for visualization of functional relations and mathematical modeling, and thus might support the process of mathematization for learners. This means that students are enabled to relate abstract mathematical models or graphs of dependencies directly to the physics phenomena. We therefore describe and apply selected tools covering a broad range of possible uses in lessons connected with these specific potentials and analyse related difficulties. We start by describing smartphone apps, which provide easy access to experiments and graphs, but do not support the active creation of mathematical models. On the other end of the range of tools, we place computational modeling tools (we chose Vpython), where students can program and build their own physical–mathematical models and visualize them. In the middle between these two extremes we could place GeoGebra, a primarily geometric tool that offers a wide range of applications and can be used for active modeling as well as for applying and interpreting given or known models.

As smartphones are meanwhile a normal tool in everyday life and nearly every student has access to it, it offers itself for manifold usages in the physics classroom. Here we concentrate on the possibilities for experimenting with help of the in-built sensors. For this purpose, a big range of apps is available in the different app-stores that visualize the sensor data. To use these smartphone apps efficiently in the classroom, it is important to know how students can handle the diagrams resulting from experiments with the in-built sensors. In this case the focus lies on interpreting the acquired data with suitable models within a given physics context.

Another type of digital tools is the dynamic mathematics software GeoGebra [1]. Perhaps better known for its computer versions, GeoGebra can be used by physics teachers from primary school to university level to create simulations, augment real experiments, and/or directly involve students in the process of creating mathematical models of physical phenomena [2]. All these types of activity require the sense making of mathematical structures in physics contexts [3].

More advanced competences include students to be able to work with computational models. Environments such as Vpython [4] enable students to construct theoretical models and to compare them to physical phenomena. This also requires appropriate preparation of teachers.

In the following, we will first describe the mentioned digital tools in detail before we shed light on some implementation schemes.

2 Selected Digital Tools: Potential and Difficulties

Apps for phones have been developed that allow data collection from the phone's internal sensors and facilitate video analysis and stroboscopic recordings. These apps allow the user very quickly to get information about the measurement in form of a graphical representation. The apps used in this study were Phyphox [5] for use of the phone's internal sensors and Vernier Video Physics [6] and Vianna [7] for the video analysis.

The app Phyphox makes it possible to use the sensors in a phone or a tablet for experiments [5]. The app is available for free both on Android and on iOS. It was developed at the RWTH Aachen and has found a wide application at university physics courses and at school for simple phone experiments. Within the app it is possible to choose between the raw sensors (acceleration, gyroscope, location, light sensor, magnetometer and pressure sensor), acoustics experiments like audio amplitude and spectrum, Doppler effect or tone generator and prepared mechanics experiments (centripetal acceleration, pendulum experiment, spring oscillator and measurement of energy loss during inelastic collisions). It is possible to create a customized experiment in the app and to export the data for further analysis. The app does an automated data analysis, and the output is a numerical value or a graph.

Vernier Video Physics and Vianna are both apps for video analysis working on the iOS. They make possible the video analysis of pre-recorded motions and create distance-time and velocity–time graphs. In order to create the graphs, the user needs to do following steps: (1) record the motion of a ball, (2) choose the position for the origin of coordinate system, (3) use the scale in order to determine the real distances and (4) mark points or track the object in motion. The programs do all calculations and the user obtains the graphs of motion.

The previous examples demonstrate the use of digital tools to construct measurement models of data as well as to collect and interpret data [8]. Digital tools can also be used to bridge or connect these data and other real-world phenomena to mathematical and theoretical models, derived from the laws of physics. Recently, the dynamic mathematics software, GeoGebra [1] has received attention in physics education [9], due to the fact that it enables teachers (with or without programming knowledge) to create their own mathematical models of physical phenomena such as simulations and to design engaging learning environments that enhance students' cooperative learning about mathematical models of physical phenomena [10].

GeoGebra incorporates geometry, algebra, calculus, and spreadsheets into a single package, creating a dynamic connection between all these different mathematical representations. For example, the user can insert expressions or equations into the 'algebra window' which will be automatically, dynamically rendered in the 'graphical window' and vice versa. In this way, the process of modeling physical phenomena involves mainly the implementation and manipulation of mathematical representations. One advantage of GeoGebra when compared to the coding or the inserting of already existing coding sequences is that GeoGebra only requires prior understanding of the mathematics itself rather than specific programming knowledge [11]. In addition, GeoGebra can also be used as a video analyzing tool, that is capturing and/or opening a digital video file of experiments and then analyzing the motion of objects in the video. This way of using GeoGebra is related to the ways the phone apps described above are used. The major difference is that while data can be collected automatically by using the phone's sensors, in GeoGebra the data is collected separately and then inserted manually.

GeoGebra can be freely downloaded from its website, www.geogebra.org, or it can be used online. It works on many operating systems such as Windows, macOS, and Linux, on tablets and phones [11] and is multilingual in its menus and its commands [12]. GeoGebra is also a community-supported learning environment. At the time of writing, GeoGebra's library, www.geogebra.org/materials, contains many numerous educational materials uploaded by its users. Most materials designed for physics education are simulations of physical phenomena and are intended primarily for secondary school education. However, as the tool allows teachers to design custom-made simulations, to modify the existing ones, and augment real experiments, GeoGebra can be used at all levels of education—from preschool to advanced university courses [2]. One of its big advantages is that it allows the students to change the values of the variables, thus stimulating to reflect on the validity of the physics law in question. The simulations and other educational material can be used for classroom activities, homework, and for online learning.

One step further in modeling would be to introduce computation into introductory physics courses. This can provide students with opportunities to create and explore computational models and to visualize abstract mathematical concepts. Several programing environments were designed in the past few decades to suit the needs of undergraduate physics students, such as M.U.P.P.E.T [13], Netlogo [14], and EJS [15]. The computational modeling platform Visual Python (VPython) is a 3D graphics system developed by Scherer, Sherwood and Chabay [4]. It is an extension of the Python language that is relatively easy to learn and use providing the user with the ability to model three-dimensional scenes. The strength of VPython is that it minimizes the amount of programming constructs the students have to learn: They do not need to get into the detailed syntax of building the display environment. Other advantages of VPython include the matching of the basic program constructs to key physics constructs (i.e., vector notation) and the straight-forward animation method (motion is generated using loops, updating objects' position).

Figure 1 shows an example of a Vpython program that models a ball under gravitational and drag forces. The program represents the ball, its trace of motion and the updated position-time graph (https://www.glowscript.org/).

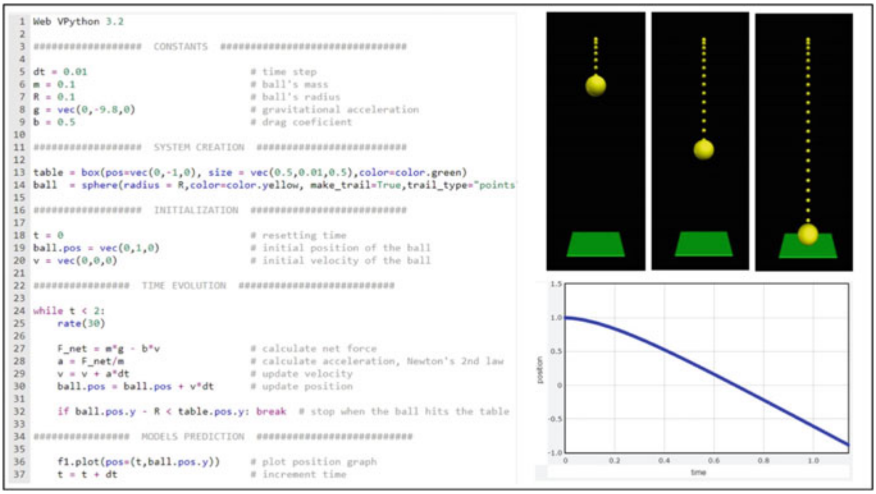

Fig. 1 A computational model of a ball falling in air, executed in the Vpython platform. The code itself is displayed on the left, and an animation of the modelled object and a position-time graph on the right. Copyright (C) 2011 by David Scherer and Bruce Sherwood

3 Status of Research and Theoretical Background

3.1 Visualization, Modeling and Mathematization

As shown in the section above, digital tools are often used to create mathematical models of data collected from the physical world or to create idealized models of physical phenomena [2, 4, 13, 15–18]. The resulting models are mathematical representations (i.e., formalism) of the phenomena displayed on a computer or phone screen. Thus, mathematization is an integral aspect of physical modeling and the digital tools used for creating the models are foremost visualization tools. In addition, digital tools can facilitate students' transition from experience to mathematical models and vice-versa by acting as a type of 'catalyst' between the physical world and the mathematical world. To explore how digital tools provide access to formal physics ideas, a chapter by Euler et al. [19] drafted for the forthcoming International Handbook of Physics Education Research, synthetizes the physics education literature related to the interplay of visualization and mathematization in physics education, specifically in the context of using digital tools.

Within this project, in order to describe the work related to the interplay of digital visualization and mathematization in physics education, the modeling framework of Hestenes [20] was combined with diSessa's (1988) perspective of semi-formalisms in physics learning and Uhden et al.'s [21] theory of modeling with degrees of mathematization (Euler et al. [19]). To highlight the interdependence between the physical domain and a mathematical domain (i.e., formalism), Hestenes [20, 22] describes the process of doing physics as a ‘modeling game’. During this process, physicists move between the physical and the formal domains as they use mathematical representations to describe the structure and dynamics of a physical phenomenon, and, not least, interpret how the mathematical model represents the phenomenon at hand [22]. To describe how digital tools can assist students during this mathematization process, diSessa suggests that digital tools can act as semi-formalisms for students by enabling the transition from personal experience of the physical world to formalisms and vice-versa. Such semi-formalisms allow students to control and manipulate certain variables connected to the physical phenomenon which is being modeled, acting as a ‘catalyst’ in students’ learning processes [23]. However, in the process of constructing a mathematical model of a physical phenomena, different degrees of mathematization might occur [21]. Hence, a digital tool that assists students during the mathematization process could function as a ‘catalyst’ in connecting the physical domain and the mathematical domain or in connecting different representations within the mathematical domain. Thus, Euler et al. [19] suggest two distinct functions that visualization tools can fulfill in facilitating mathematization in physics:

Function I: bridging between physical phenomena and formalisms, by

(a) linking physical phenomena to formalisms and/or,
(b) augmenting physical phenomena with formalisms, and

Function II: bridging between idealized models of physical phenomena and formalisms by

(a) linking models to formalisms and/or
(b) augmenting simulations with formal representations.

3.2 Smartphone Apps

The phone apps mentioned above have been used for a broad variety of experiments [16–18]. In their paper, Staacks et al. [16] describe the ways to use Phyphox in a rolling experiment and an elevator experiment. For the elevator experiment, the phone is put on the floor of an elevator and the movement of the elevator is tracked using the phone’s atmospheric pressure sensor and its accelerometer. The height differences are then calculated using the recorded atmospheric pressure. The (numerical) derivative of these height values gives a vertical speed and the accelerometer directly provides the vertical acceleration of the elevator. As a result, students get the graphs showing the altitude, vertical speed and acceleration as a function of time, as shown in Fig. 2.

Götze et al. [18] describe the use of Phyphox for two simple experiments on the simple harmonic oscillator, which can be done with high school students and Pierratos and Polatoglu describe the use of the optical stopwatch function for quantitative kinematics [17]. All those papers emphasize the potential benefit of the app for the motivation of the students, the accessibility of a variety of experiments for the students, as well as automated data analysis.

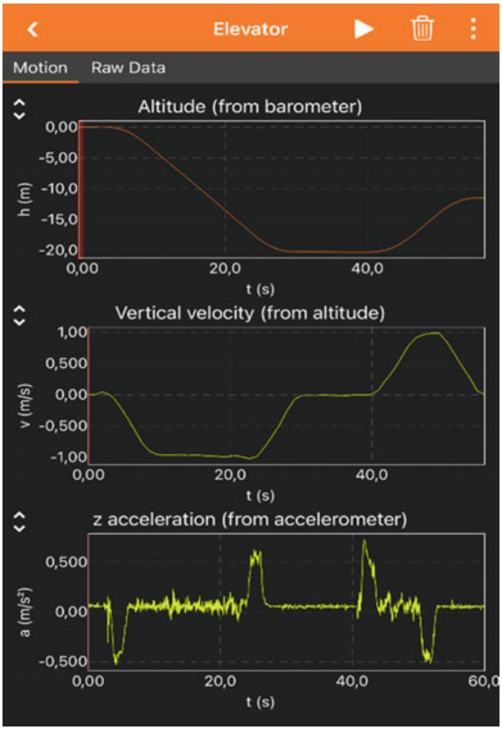

Fig. 2 Elevator experiment in Phyphox App: Three different kinematic quantitites are shown atop each other: position, velocity and acceleration. These graphs have to be related to each other and to be interpreted with respect to their physics meaning

However, up to now there is no accompanying research regarding the difficulties with reading and interpreting the graphs that students get as a result of the data analysis. Previous research on student understanding of graphs shows that a majority of students have difficulties interpreting and calculating the slope of the kinematic graphs [24–28], as well as interpreting the meaning of the area under the graph [27]. McDermott et al. detected in their research with kinematic graphs that students have the following difficulties: slope-height confusion, difficulty in making connections between different types of graphs, difficulty in interpreting the meaning of the area under a curve, difficulty in distinguishing the shape of the graph from the shape of the body's trajectory, difficulty in understanding the meaning of the sign of velocity and acceleration [24]. Leinhardt et al. have summarized the three main difficulties with the graphs as interval-point confusions (focusing on a single point of the graph instead of using an interval), slope-height confusions (when students mistake the height of the graph for its slope—just reading off the y-coordinate) and iconic confusions (incorrect interpretation of the graph as an actual picture of the motion) [28]. Although there is no research on the graphs from phone apps, it is to be expected that students could have similar difficulties, when it comes to the interpretation of the graphs generated from phone experiments. In order to exploit fully the potential of the direct visualization of experimental outcomes in graphs for bridging between the experiments or phenomena and models or formalism, these difficulties have to be precisely known and addressed in teaching.

3.3 GeoGebra

GeoGebra has been advocated as a user-friendly software that can be operated intuitively [11, 29, 30]. The studies on teaching sequences supported by GeoGebra simulations conducted by Malgieri et al. [30, 31] include a collection of GeoGebra simulations developed by the students or by the researchers to assist students in learning quantum physics at a basic level based on Feynman's sum over paths' approach. The studies show that by using these teaching sequences, students have improved their understanding of several conceptual issues and their ability to use the 'sum over path' method for problem-solving, as well as their ability to express themselves using an expert-like language. Regarding the collection of simulations and the software used for designing it, the researchers consider that GeoGebra is a valuable supporting software as it 'makes the mathematical models behind the simulations completely transparent and easily accessible to the user, and avoids producing the impression that complex and exotic algorithms are at work' [30]. A study conducted by Solvang and Haglund [32] analyses specific bodily practices (e.g. gestures, enactment) during students' interaction and constructions of representations in relation to a GeoGebra simulation of friction. The simulation represents a block sliding over a horizontal surface. The block is pulled by a hand holding a dynamometer, which shows the value of the pulling force. Simultaneously, a force–time diagram is displayed. Students could change the materials of the block and the surface, the value of the block's weight, and the base area. They could also start and pause the simulation or reset the graph. During their sense-making processes, students were triggered by specific features of the simulation—features connected with microscopic aspects of friction—to improvise their own representations as means of dealing with interpretational problems. For example, one of the students exaggerates the intermittent movement of the block caused by the protuberances of two rough surfaces by enacting the movement of a jumping frog and making choo-choo train sound effects. During their sense-making processes, students moved back-and-forth between the mathematical model of friction and the physical world of gestures and enactment, while the software was used as a catalyst in students' learning processes. With a simple push of a button, students could test and compare their ideas, the mathematical model, and their improvised bodily representations as the mathematical model could be reproduced dynamically in real-time.

3.4 Computational Modeling Environments

Computational modeling environments have been shown to enable secondary students to construct theoretical models for a variety of phenomena that are too complex to be modeled analytically, and compare them to experiments [33, 34]. As pointed out by Tang et al. [35] secondary school inquiry often emphasizes the experimental aspects of research and lacks the theoretical modeling aspect that is critical to the physics research process. Computational modeling can provide a solution to this challenge and overcome students' limited mathematical knowledge using step-by-step computational methods.

The computational modeling environments that were described above [13–15] have been designed and implemented in undergraduate physics courses. These courses are typically taught by researchers who are familiar with computational tools, at least to the extent required of their students. When integrating computational activities into school courses, we must consider the teachers who often lack programming skills and whose self-efficacy in this field is low, perhaps even lower than that of their students [36–38]. In computational activities for students in introductory physics courses, the learning goal is to create autonomy in constructing the computational model. Is it possible to reduce aspects of this autonomy in modeling activities for high school students—so that they can be adopted by high school teachers?

One possible way to increase teachers' sense of competence is through activities that aim to attribute to the understanding of an existing program through its activation and manipulation, without having to write its code. This differs from working with pre-built simulations, as learners can 'open the hood' of the model and understand the implementation of the physical laws and Euler's approximation method in the computer code. We adopted this approach, and report on the design and implementation of a sequence of computational modeling activities using Vpython in an inquiry-based workshop for 9th grade physics teachers.

4 Interpretation of Graphs Generated by Phone Apps

We investigate how students understand and interpret graphs generated by phone apps in order to identify if there are specific difficulties in addition to the known problems in interpreting kinematics graphs.

4.1 Research Questions and Method

The main research questions for the interpretation of graphs generated by phone apps were:

1. What are the main observed students' difficulties with graphical representations from phone apps?
2. What are similarities and differences to already reported students' difficulties with graph interpretation?

To investigate how future physics teachers can deal with graphs and images from phone apps and to answer these questions, a questionnaire with a total of 7 open-ended questions was developed and given to a total of 58 students from TU Dresden and 55 students from University of Vienna. The allocated time for taking the questionnaire was 45 minutes. The questionnaire contains graphs from the apps Video Physics, Vianna, PhyPhox and Sony Motion Shot. Two questions were related to the graphs from video analysis of the motion (free fall and a ball rolling on the incline), three graphs were generated with the app PhyPhox [5] using the internal smartphone sensors (elevator, rotational motion and motion of a car) and two representations included stroboscopic images of the motion. The students had to read different physical parameters from the graphs and analyze the graphs. The answers were analyzed and categorized using the framework of qualitative content analysis by Kuckartz [39] to find out the most common difficulties with the representations from phone apps. In the subsequent chapter, two examples will be discussed: the free fall example and the elevator example.

4.2 Results

Free fall question. The question shows the graph from the video analysis program Vernier Video Physics for a ball that has been released from the hand and falls to the ground and bounces back. Students were shown the video of the experiment, as well as the position-time and velocity–time diagrams that are the result from the video analysis. Based on the graph students were asked to determine the acceleration of the ball at the moment t = 2,5 s. This moment is the turning point of the ball. The main strategies that students used were:

- calculating the slope from the v-t diagram
- stating that the acceleration equals g, because it is the free fall situation
- stating that the acceleration is zero
- using the wrong sign for the acceleration

The correct strategy included calculating the slope from the v-t diagram. 10% of the students from TU Dresden and 18% of students from University of Vienna used that strategy. In addition, 28% of students from TU Dresden and 22% of students from University of Vienna concluded that the acceleration is 9,81 m/s^2, because of the free fall and due to the gravity. Although this is a right answer, those students were not using the graphs at all. Most of the students (30% of students from TU Dresden and 35% of students from University of Vienna) said that the acceleration of the ball is zero. Their explanations included the use of the wrong formula (a = v/

t) and slope-height confusion (because the velocity is zero, the acceleration is also zero).

Elevator question. The question shows the graph from the app Phyphox and the height-time, velocity–time and acceleration-time graphs for a motion of an elevator that first goes downwards and then upwards, as shown in Fig. 2. Students were first asked to detect when the elevator is moving in which direction and afterwards when the elevator is speeding up and when slowing down. The main correct strategies that students used were reasoning based on the v-t graph and the direction of motion or reasoning based on the a-t graph and direction of motion. In the sum 33% of students from TU Dresden used that strategy, as well as 31% of students from University of Vienna. The main wrong strategy was linked to the idea that the elevator is speeding up when the acceleration is positive and slowing down when the acceleration is negative (used by 21% of students from TU Dresden and 31% of students from University of Vienna), followed by the reasoning that the elevator is speeding up or slowing down only when the acceleration changes its value. Other difficulties included the thinking that the elevator is always speeding up or slowing down. Additionally, difficulties with non-idealized graphs, and interval-point confusion were observed.

5 Implementation of GeoGebra to Facilitate Mathematization

In this section, it is highlighted how digital technologies could perform the role of semi-formalisms. In the following, GeoGebra is used as an example of a digital tool which can facilitate mathematization through Function I and Function II, described above [19]. We illustrate the two mathematization functions with GeoGebra, which unlike many other visualization tools used in physics education can flexibly exemplify both mathematization functions depending on how it is implemented.

Function I: Bridging physical phenomena and formalism

(a) by linking physical phenomena to formalisms:

GeoGebra can be used as a video analyzing tool, that is capturing and/or opening a digital video file of experiments and then analyzing the motion of objects in the video. This way of using GeoGebra is related to interactive video. Users can also insert just a picture of a phenomenon, such as a basketball being thrown into a hoop (Fig. 3). Different positions of the ball at different times are already being marked in the picture. The equation of the fitting curve contains three sliders, *a*, *h* and *k* as coefficients. Because of the dynamic link between algebraic and graphical representations of an object, realized by dragging the sliders, the user can find the equation for the graph that best fits the trajectory of the ball.

(b) by augmenting physical phenomena with formalisms:

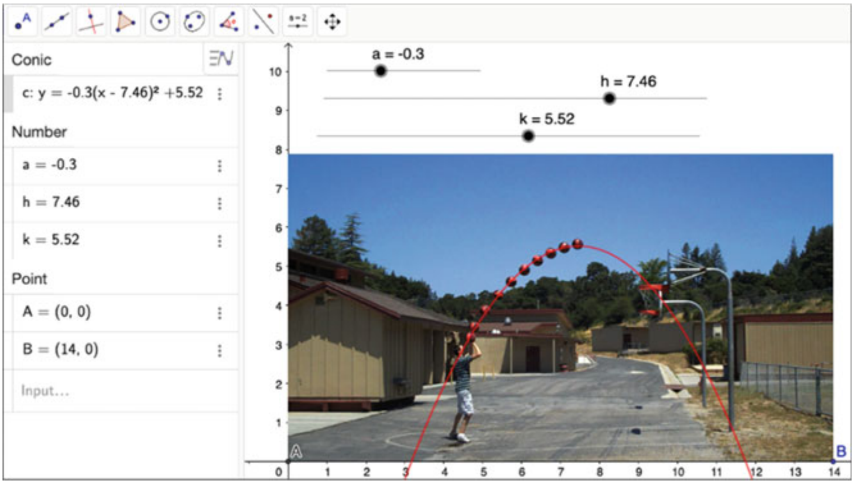

Fig. 3 Linking physical phenomena to algebraic and graphic representations using a GeoGebra simulation of a projectile motion, freely available at https://www.geogebra.org/m/pgqKNSak)

GeoGebra can also be used for augmenting physical phenomena. If a computer or phone has a camera, virtual objects, such as force arrows and light rays, can be constructed with GeoGebra and then accessed with GeoGebra 3D Calculator by pressing the tool's AR button. For example, the motion of an object on an inclined plane can be augmented by a dynamic GeoGebra model of the resulting force (Fig. 4).

The model displays the resulting force as the vector sum of the gravitational force and the normal force. The mass of the cart and the angle of inclination can be modified to correspond to the real setup (Fig. 4).

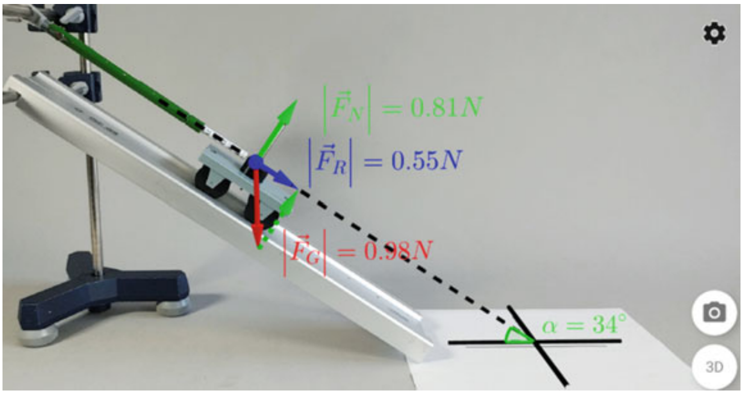

Fig. 4 Motion of an object on an inclined plane augmented by a dynamic model constructed in GeoGebra (reproduced with the permission of the authors from Teichrew and Erb [40], and available at www.geogebra.org/m/pafx6xfu#material/qhb4yeht)

Commands	Results
$\alpha = 25°; v\_0 = 1.6; g = 9.8; L = 7; t = 0; O = (0, 0)$	Defining system parameters
a = g*sin(α)	Defining acceleration
$d = V\_0 * t + 1/2 * a * t\^2$	The displacement at time *t*
t_f = (−V_0 + sqrt(2a*L + V_0²))/a	The time required to cover the distance *L*
M = ((L − d)*cos(α),(L − d)*sin(α))	The position of the body at time *t*

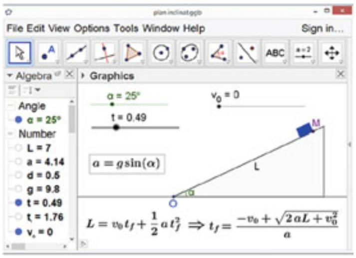

Fig. 5 GeoGebra screenshot showing the algebraic representations (left) and the idealized geometrical model (right) of an inclined plane (reproduced from Marciuc et al. [41] with the permission of the ADL ROMANIA)

Function II: Bridging idealized models of physical phenomena and formalisms

(a) by linking models to formalisms:

This simulation made in GeoGebra exemplifies the second function of visualization. It presents an idealized geometrical model of a block being pulled across a frictional surface (Fig. 5 right). To create this simulation, the user needs to insert the algebraic representations of all the geometrical representations (Fig. 5 left). In addition, relevant equations which describe the motion of the block can be inserted into the geometrical widow. The users can then manipulate the relevant parameters, such as the angle of the inclined plane and observe a dynamically generated motion of the block.

In all examples above, GeoGebra can be seen as a tool that ostensibly facilitates students' transition between relatable physical phenomena and the formalisms that the discipline of physics uses to mathematize those phenomena as part of problem solving and analysis.

6 Professional Development of Physics Teachers with Computational Modeling

We report on the design and implementation of a sequence of computational modeling activities using the Vpython platform in an inquiry-based workshop for 9th grade physics teachers. We focus on two research goals: (1) Characterizing design guidelines for computational modeling activities that enable teachers without programming expertise to successfully complete them in a limited time frame of a workshop. (2) Examining teachers' perceptions of the affordances and challenges of the computational modeling activities they experienced.

6.1 Research Approach

In order to characterize design guidelines for computational modeling activities that are manageable for 9th grade physics teachers (Research Goal 1), we examined two designs of the activity. The pilot design was tried out twice, in the summers of 2017 and 2018. The final design considered the feedback from the pilot version and was tried out on the summers of 2019 and 2020. The versions were tested based on two main measures: teachers' ability to complete the activities in the limited time frame that could be devoted to computational modeling in an inquiry-based PD workshop, and the extent of classroom implementation. To learn about teachers' perception on the activities (Research Goal 2) we used questionnaires and open-ended questions to reflect on the final version of the computational sequence.

6.2 Context

Gateway to physics is an inquiry-based program intended to motivate 9th grade students to choose physics as a major by increasing their interest and self-efficacy, as well as the self-efficacy of their teachers. Two learning modules were developed, both investigating straight-line motions under acting forces. The 1st module dealt with oscillations of a mass on a spring and the 2nd with objects falling in air. During the summers of 2017–2020, the modules were introduced in PD workshops (30 h over 4 days for each module) for teachers from a variety of disciplinary backgrounds. The first two days of the workshop focused on experimental investigations and the last two days on theory, discussing the related theory qualitatively, and using computational modeling to overcome mathematical complexity (both systems involve nonlinear equations) and produce quantitative models and predictions.

6.3 Design of Pilot Version

The activities were designed as a middle ground between using ready-made models and writing models from scratch. Our approach was to 'open the hood' and allow students to observe a working computational model, understand the function of each line of code, and then modify it according to their needs. The activities did not address the algorithmic considerations of the underlying program. Two activities served as an introduction to the computational activities. The first introduced the motivation for computational modeling: Teachers used structured worksheets to discuss the possibility of predicting motion in different situations, and the second introduced Euler's step-by-step computational method. The computational activities were carried out using Trinket.io—a free online tool for programming activities and courses. This platform runs Vpython—a 3D graphics package for Python, a widely used programming environment for scientific modeling. The sequence consisted of 4 activities:

1. Acquaintance with the programming environment—where students learn to create different objects and place them.
2. Constant velocity motion—students are introduced to the "while" loop and its use to move objects at constant velocity.
3. Motion under a constant force—students learn how to apply Euler's method to construct models of motion under constant forces based on Newton's second law of motion.
4. Comparison of model and experimental results—students produce a theoretical trace of the motion of objects, compare it with an experimental trace they created using the Tracker video analysis software [42], and revise their model to better fit experimental data.

Participants received minimal instruction, and learned the meaning of the different parts of the program through hands-on tasks. For example, in the constant velocity activity, they were shown a ball moving from the right side of the screen to the left and were asked to make it move in the opposite direction (requiring a change in the direction of velocity and in the initial position of the ball).

6.4 Findings—Pilot Version

53 teachers participated in the pilot activities. We witnessed a high dropout rate: ~20% of teachers did not complete the entire sequence of activities. Most of them had no prior background in programming, resulting in low self-efficacy. Among the teachers who did complete the activities, only a few implemented them in their physics classes, either due to external constraints (inadequacy to the curriculum, lack of computers or time) or lack of confidence to adapt such an innovative curriculum.

6.5 Design of Final Version

The results of the pilot study showed that reducing autonomy in writing the code was not sufficient, as the teachers expressed low self-efficacy and frustration. To enable more teachers to successfully accomplish the computational activities we revised the activities, using the scaffolding mechanisms of structuring and problematizing [43]. Each activity was divided into the following three steps:

1. Exploring an existing program by running it, making guided manipulations and describing their outcome.
2. Sense making of the program and the role of each command through guiding questions.

3. Application: modification of the code to meet different tasks.

For example, the mechanism of a simple loop is presented through: (1) Exploring—students run a loop that counts from 1 to 10 and describe the outcome of small changes they are guided to make. (2) Sense making of the components of the program through guiding questions, such as what is the role of the code line ‘while m < 10’. (3) Application—students are required to change the program, so it counts to 20 or by jumps of 3.

Another revision made in the final version of the activities had to do with the comparison of the computational and experimental models. Models were compared through various mathematical representations: tables, velocity–time graphs, and traces of motion instead of only comparing the traces. In addition, the activities were incorporated into the same learning management system as all other PD activities—a Moodle-based platform the teachers were familiar with, instead of an external platform, to help teachers view the unit as an integral part of the workshop and avoid switching between platforms.

6.6 Findings—Final Version

67 teachers experienced the refined activities during the summer of 2019 and 2020. The final version of the activity was successful in keeping the teachers engaged: previous research [44] showed that the 2019 teachers reported higher programming self-efficacy after completing them. In the 2020 PD workshop, teachers successfully completed the activities—only 1/18 dropped out. Furthermore, they appreciated the activities as contributing to their understanding of the theoretical as well as the experimental aspects of the inquiry process:

> I really liked the perspective it gives, the digital “calculation” so you see results and graphs that come out… but while here we will get accurate and perfect graphs in the experiment we will get slightly different graphs, which gives us another way of understanding measurement errors in experiments
>
> Through the step-by-step solution of Newton’s second law, without going into the concept of acceleration, made me re-examine my ways of teaching inquiry... step-by-step analysis develops students’ good understanding of motion

However, most of the teachers (~75%) stated they still do not feel confident enough to implement the activities in their classrooms, mainly due to insufficient expertise in the programming environment.

7 Conclusion

We have described a possible theoretical framework concerning the relation of visualization and mathematization in physics with respect to selected digital tools. Normally, great expectations are placed on the supportive effect of these well-known tools for physics understanding. However, less is known about students' actual experiences with these tools. Our paper offers valuable design guidelines for implementation, as well as empirical results, indicating that a certain degree of precaution is advisable here. Students show clear problems in interpreting graphs that are generated by the corresponding apps, for example, when experimenting with the phone. This observation is coherent with previous research on interpreting graphs. It has to be considered also that the task is quite complex: students have to relate experiment, physical understanding and the characteristics of the graphs to each other in order to arrive at a correct interpretation. Difficulties known from the literature are observed, such as slope-height confusion or the inadequate differentiation of acceleration and velocity. In addition, specific difficulties e.g. connected to the fluctuations of experimental values were observed. Thus, when using such apps, the teachers must be aware that the interpretation of the graphically represented results from the experiments requires numerous steps done by the learners. Such problems can also arise in the case of GeoGebra. In this case, however, the possibility of switching between different representations with a simple click could support in interpreting the graphs and understanding the physical models. Comparable observations are made in the context of a computational modeling environments. While the mechanisms of structuring and problematizing [43] have helped teachers to make sense of the theoretical models and their implementation in a Vpython program, and to appreciate the potential of computational modeling to physics learning, it seems that there is still a long way to go in mastering this skill well enough for them to confidently implement this method in their classrooms. Overall, it is observed that in order to exploit the potential of digital tools in the context of mathematization, the teachers have to be aware of the pitfalls and have to be able to diagnose the arising difficulties, for which this contribution provides guidance. Taking those into account, the use of digital tools could enhance physics understanding and help to apply mathematical tools.

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Symposium on Teaching and Learning Quantum Physics

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Abstract The advancement of quantum technology is putting in the spotlight the question of quantum awareness or quantum literacy among the general population. Therefore, initiatives have been put forward to bring quantum mechanics to pre-university level. Some countries entered quantum mechanics in their regular high school curriculum, and some did not. Various approaches have been developed with varying success. The symposium brought together experts with experience teaching quantum mechanics at high school and introductory university levels. Following the logic of creating a curriculum, various considerations have been identified that play a role in what approach a particular instructor chooses. A main difference emerged between making connections with classical physics using potential wells and barriers as context versus breaking up with classical physics using quantum technology as context. The article presents a synthesis of the discussion on what to teach, how to teach, how to choose between different approaches and how to prepare teachers.

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Keywords Teaching and learning quantum mechanics · Representations · Teacher training

1 Introduction

Quantum physics and its implications for future science and technology is becoming culturally important and more attention is being given to its introduction before university level [1, 2].

There is rich literature about different approaches and strategies [3]: (1) historico-philosophical, (2) matter-wave, (3) two-state systems, (4) Feynman path integrals, (5) quantum field theory, (6) quantum technology, which have been all adapted for pre-university level. Further differences are in: (a) contextual aspects: e.g. choosing a spin, polarization or double well two-state system, and (b) methodological aspects, using frontal traditional presentation or active engagement methods. All approaches show learning gains among students.

Given the diversity of approaches, there are growing efforts [4] to identify key concepts to be taught and key competences to be learned hinting that all approaches might not be equally suitable to introduce all concepts. To address these issues, a symposium has been organized. The symposium has been structured to follow the construction of a curriculum, starting from the expected prior knowledge, passing through teaching methods, pedagogical considerations and available tools to arrive at an example of an implementation including teacher training. Four participants and a discussant have been invited in base of their expertise in the field. The key questions to answer were:

- What are the key concepts that students should learn in quantum mechanics courses designed for non-physics majors?
- What tools and strategies help in achieving the learning goals?
- What are the challenges and opportunities of teaching quantum mechanics to high school students and non-physics majors?
- What are the considerations taken into account when choosing a particular approach to teaching and learning quantum mechanics?
- How to prepare teachers to teach the topic?

It emerged from the symposium that several of the answers are dependent on a set of considerations about the goals and structure of the course. In their contributions, each participant addressed several of the above topics as they relate to their particular experience. From this, a synthesis emerged that is described in this article.

The article starts with theoretical frameworks about teaching and learning so that various suggestions and examples from participants can be adequately framed in the context of these frameworks. Then the answers to the questions posed above are discussed, as they emerged from the presentations and the following discussion. In the end, a discussion is presented about the potential open questions for further research.

2 Theoretical Frameworks

The symposium revealed that there are multiple theoretical frameworks being used when assessing the educational strategies regarding quantum mechanics. Different aspects of teaching and learning require consideration of different frameworks of teaching and learning.

Starting from the introduction of the completely new physical laws encountered in quantum mechanics it is important to consider student prior knowledge. The *Knowledge in pieces* framework derived from the works of diSessa [5] and Hammer [6, 7] interprets knowledge as being constructed from small pieces called reasoning *resources*. These are rules that are applicable to a variety of situations, such as peaks of waves add up, but are often not applicable universally. According to this framework, many of student difficulties arise from inappropriate activation of otherwise useful resources. An example from mechanics is the "force is proportional to velocity" resource. This resource is adequate in cases where drag is involved. And students' experience of these cases is vast (cycling, cars, dragging objects through water or even pushing a cart to some degree). It is no surprise then that students activate this resource also in cases without friction and drag. In fact, they have much less experience with such examples, so Newtonian mechanics where force is proportional to a change in velocity is much more foreign to them. An important element in the activation of the resources are triggers. If the student learns to trigger the "force is proportional to velocity" resource in cases with drag, but activate the Newtonian mechanics resource in cases without drag, they will be more successful. In this framework, the goal of physics is to provide as universal resources as possible and for students to adopt them as much as possible. With proper application, Newtonian mechanics works in cases with drag as well as cases without drag. Another source of student difficulties according to the Knowledge in pieces framework are inappropriately constructed resources. According to the theory, resources are constructed from experience. Students gradually learn the rules and contexts and construct a sort of network of triggers and rules that gets activated as a single resource. This new resource can be constructed from older resources or completely anew. But if students are not exposed to enough different situations where the resource applies, their resource might be incomplete. The peaks add up resource is applicable to explain the interference pattern, but when asked to explain the shape of a single pulse superimposed on another pulse, students often sum up only the peaks, not every point of the pulses [8]. This is likely due to the fact that a resource about summing the pulses point by point was not constructed. Exposing students to these kind of tasks helps them build up more complete resources.

The next step is acceptance of the newly constructed knowledge. According to *Chi's theory of conceptual change*, there are three *ontological categories*: entities, processes and mental states [9]. An important element of conceptual change is the correct classification of new concepts. An example from waves is that students classify a pulse as an entity instead of a process. Then they talk about pulses bouncing off each other or engulfing each other, much like colliding carts [8]. Conceptual change occurs when reclassification occurs. But in quantum mechanics, duality is an example, where classification within the three ontological categories becomes impossible. Either a new category must be created or severe conceptual difficulties are to be expected.

Another challenge in learning quantum mechanics is the acceptance of the theory. It has been observed that students do not have problems learning the rules of quantum mechanics, but do have problems accepting it, because it is counterintuitive to them [10]. According to *Posner's theory of conceptual change* [11], for a concept to be accepted, it has to be understandable, logical and useful. The logical part is most challenging. Since students are associating quantum mechanics with the real world, they expect the theory to be consistent with their classical view. The fact that it is not creates cognitive conflict. Two ways have been proposed to address this conflict. One is to enhance student knowledge of relevant topics in classical physics to help them connect at least parts of quantum mechanics to their prior classical concepts [12]. The other is to start completely anew, treating the quantum world as a *quantumland* with its own laws.

All these frameworks have to be taken into account when designing learning sequences in quantum mechanics. In the following chapters we discuss how they are reflected in the answers to our symposium questions.

3 Methods

The participants of the symposium were selected based on their long standing involvement in the field and their expertise in the topic. They were asked to submit a contribution about what they consider important about teaching and learning quantum mechanics. The symposium questions were identified from their contributions. In the symposium, the participants addressed one or more of the questions in their presentation. Different perspectives on each question have been identified, analysed and summarized by the discussant. In the Results section we address each question separately and attempt a synthesis of the views of the participants.

4 Results

4.1 What to Teach?

The question of what to teach was approached from three sources, one is an overview of European high school quantum curricula [2], another is the consensus achieved in the Quantum Technology community [13] and a third is the consensus reached in the 2019 workshop of the GIREP community on teaching and learning quantum physics [3]. Table 1 shows a summary of the concepts.

Table 1 An overview of important topics to tech as emerged from three sources, an overview of current curricula, a Delphi study with experts in the research field (QT framework) and a consultation between physics education experts (GIREP community). The scores are given in percentages of the total number of surveyed people/curricula in each survey, if given in the source

	Curricula (%) [2]	QT framework (Y/N) [13]	GIREP community (%) [3]
Discrete energy levels (line spectra)	79	No	0
Interactions between light and matter (photoelectric effect)	82	No	0
Wave-like representations	91	Yes	75
Measurement	0[a]	Yes	100[a]
Wave-particle duality	91[a]	No	100[a]
Matter waves (de Broglie)	82	Yes	0
Superposition	0	Yes	75
Technical applications	58	Yes	50
Uncertainty principle	61	Yes	75
Probabilistic predictions	61	Yes	100
Nonlocality	0	Yes	50
Philosophical implications	33	No	75
Nature of science	100	No	50

[a] In Ref. [3] measurement and wave-particle duality have been classified together with the rationale that the particle-like interactions of quantum entities can be considered the consequence of collapse after measurement. In Ref. [2] measurement is not mentioned

As can be seen from Table 1, there is some disagreement about the core concepts that students should learn. This stems from the goals and approaches that the participants envisioned. For example, a wave-like description is irrelevant for a two-state system. Similarly, the Nature of science goals are very important in school curricula, but overlooked at the level of experts, probably assuming that they would be learned in other contexts. One pattern that can be seen from Table 1 is that the wave-like description of matter seems to lose its importance as the goals shift away from a historical and philosophical perspective towards a more pragmatic and contemporary quantum technologies perspective. The choice of topics will be discussed again in the section about the choice of approaches.

In some countries, quantum mechanics is not defined in the core curriculum, in others it only amounts to developments before 1925 [2]. In these countries it can be either taught as an extracurricular activity or in the context of non-compulsory topics within regular classes. In these cases, the choice of topics depends on the teachers and their goals.

Despite some disagreement on what to teach, there is strong consensus on how to teach. An overview of teaching tools and strategies [1] shows that teaching quantum mechanics is generally efficient if done with multiple representations, in an active engagement environment and making the core concepts very clear and accessible. To this end, in the symposium Heusler proposed to focus on models using multiple representations, focus on interpretations with conceptual clarity and technical terminology, focus on conceptual understanding, using mathematics and visualization tools, and focus on activities by looking for accessible experiments and simulations. Bondani further conceptualized the same ideas in the following way: *core concepts* are derived from experiments, and are defined and described with representations, representations are used to analyse and interpret experiments, and successful description or modelling of experiments leads to the definition of *axioms*. In this context, axioms are rules formalized in a mathematical language, that can be used to explain the outcomes of the already observed experiments and predict outcomes of new experiments. They are a formalization of the core concepts.

Krijtenburg-Lewerissa emphasized that sometimes curricula are predefined and in this case the question of what to teach becomes moot [14]. The Dutch curriculum focuses on wave-particle duality, the infinite potential well, and tunnelling. Therefore, it is important that students understand the related physics. Krijtenburg-Lewerissa then presented a research into how students' prior knowledge of potential energy influences their learning of quantum mechanics [14]. Surprisingly, positive effects have been observed already in the pre-test before any instruction on the quantum. The effect of an additional module about potential energy has had small, but significant positive effects on all aspects of learning quantum physics.

From the analysis in Table 1 and the contributions in the symposium, it became clear that instructors generally decide between two very different approaches. Either they start from scratch and treat the quantum world as a quantumland with its own rules still to be discovered [15, 16], or they start from the known, attempting to build bridges between classical and quantum [14, 17].

The quantumland approach allows students to disconnect any of their prior knowledge from the quantum world [18]. This opens the question whether it may be more useful in this case, that the choice of the context is also something students do not know from the classical world, such as spin or polarization, rather than something familiar like position and energy in a double well. This question remains to be answered in future research. When instructors choose this approach, they usually start from various observational experiments. These may include observing light passing through differently oriented polarizers [19], a polarizing Mach–Zehnder interferometer [15, 20], particles with spin passing through a Stern-Gerlach apparatus [21] or simulation of particle detection in a double well [16] to name just a few. The topics are typically indeterminism, superposition, effect of measurement, uncertainty principle and then either towards quantum technologies such as computing and cryptography [15] or towards more derived concepts such as entanglement, "which way" questions and time evolution [16, 19].

The approach connecting classical and quantum allows students to relate their new knowledge to the already acquired knowledge potentially making the new knowledge more relevant and significant. Instructors taking this approach typically focus first on related classical concepts, like waves and potential wells. They then proceed towards adding quantum elements to an already familiar environment in form of wave particle duality and/or statistical interpretation [14]. Krijtenburg-Lewerissa showed that understanding of potential wells can aid in the process. Previous work also shows how other relevant topics can be related to quantum mechanics, such as waves to wave functions [22].

The choice of what to teach is thus very dependent on the goals, but two-state approaches appear to be more aligned with the quantumland approaches emphasizing practicality and current relevance, while matter-wave approaches tend to rely more on the historical development and the philosophical implications.

4.2 Tools and Approaches

Based on all cognitive science theories accepting new hypotheses requires experience with them. Posner's theory of conceptual change requires cognitive conflict, while the Knowledge in pieces framework requires experience upon which to build new resources. It is well known that students are perfectly able to learn whatever is taught, but fail to accept it, if not given enough opportunity to test it. Back to the example of Newtonian mechanics, students are capable of learning it, but some still think it only applies in school, because outside of school they have little experience with frictionless dragless environments. In the real world, force is proportional to velocity makes more sense to them. In a similar manner, students need experience with the quantum world to be able to accept it.

Real quantum experiments require specialized equipment that is still beyond the reach of high schools. Nonetheless, there are multiple efforts to make the quantum as accessible as possible. Heusler presented an optical bench made with a 3D printer, which is affordable and designed to enable crucial experiments in optics [23]. While single photon experiments remain generally inaccessible to high school students, the optical kit offers numerous possibilities for analogous experiments, from Michelson interferometer to Mach–Zehnder interferometer. With the addition of polarizing filters an analogy to a quantum eraser can be produced. This paves the way to make the results from single photon experiments (either reported or experienced with a simulation) plausible. Thus fulfilling perhaps the hardest of the requirements from Posner's theory of making the new theory plausible.

For experiments that cannot be affordably done in class or whose results are difficult to interpret, there are multiple simulations available [24–26]. These serve to give the students an impression of inquiry. While simulations may not be particularly persuasive to "confirm" a learned theory, because the theory is obviously already built into the simulation, their potential is greater when exploring new laws of physics. In this context, while students actually investigate the laws of the simulation, they, at the same time, investigate the laws of nature upon which the simulation is built. Students and people in general have no problem accepting new, strange rules for made-up environments, like fantasy worlds or chess, so they may have little difficulty finding out the rules of the simulation. The challenge is persuading them that these rules apply to the actual world, if they appear counterintuitive to them. To address this, learning the nature of science and scientific models may be crucial and will be discussed in the next section.

An important learning tools are representations [27]. They have been addressed by all participants. It is known that using multiple representations helps learning [28]. In quantum mechanics, the already well established Dirac notation and Feynman diagrams immensely help experts to talk about complex concepts. Multiple suggestions have been made over the years about how to simplify the mathematics of quantum mechanics for the benefit of high school students or about introducing completely new notations [16, 19, 29]. However, for high school, a standardized notation has not yet been developed. Nevertheless, in the symposium it emerged that the Dirac notation might be very useful in high school, too, albeit with some modifications. This is supported by the experiences with a summer school, presented by Bondani, where Dirac notation is used [15].

Focusing more on quantum computing, they represent different eigenvalues with “1” and “0”. In addition, they use the representation with quantum gates. This representation has the advantage to clearly show which qubits are being operated upon. It also clearly distinguishes between operations on single qubits and operations on multiple qubits. Bondani showed that participants efficiently use both representations and are capable of using them complementarily.

Heusler proposed a representation involving a Bloch sphere inside a ket. This representation can be used for any two-state system. Examples given in Fig. 1 are from spin and double well, but the representation can also be used for polarization, neutrino oscillations, and mass-flavour eigenstates.

A long used representation is that of the wave function in a potential. This is more natural for the wave function approach discussed by Krijtenburg-Lewerissa. Wave functions can be very dynamic, so visualization tools are very useful in addressing any temporal components of wave functions. Heusler presented the Quantum composer [30], a visual tool used to manipulate potentials and represent wave functions. These

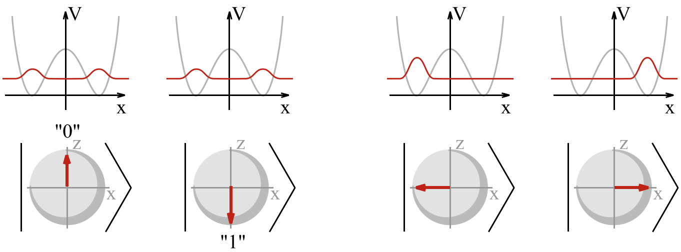

Fig. 1 States represented with Bloch-sphere kets. The figure shows how stationary and non-stationary states in a double well can be represented with Bloch-sphere kets

can be represented in multiple graphical forms, 2D graphs, 2D contour plots, etc. The strength of Quantum composer as compared to similar PhET tools [31] is in its blocks-like structure which visually represents the relations between the various elements of a quantum mechanical problem. Emigh further emphasised the importance of representational fluency in quantum mechanics instruction [32–34]. This was a major consideration in the design of their course which uses sketches to represent experiments and their outcomes, histograms to represent probabilities, Dirac notation, matrix notation and even kinesthetic representations, where students represent phases with their arms (see Fig. 2).

Heusler further proposed a topological representation of states using a belt [35] (see Fig. 3). In this model, a Moebius belt represents one possible outcome of a measurement. The Moebius belt can have either a left or a right twist, representing two possible outcomes on a two-state system. In this model, an entangled state is created by using a regular belt and twisting one part of it for 180 degrees. Spatial separation is represented by squeezing together the twisted part and a portion of the straight part of the belt creating two apparent Moebius belts, one with a left and one with a right twist. One belt is assigned channel A and the other channel B, but the assignment is random creating entanglement. If a measurement is made on channel A, one gets either a left or a right twisted Moebius belt. A measurement done on the other channel would reveal anticorrelation.

It was a consensus among participants that the appropriate notations and representations are crucial to develop conceptual understanding among students. Especially, there appears to be no need to shy away from the Dirac notation, as it can be easily adopted by students of all ages. There is, however, necessity to investigate what type of symbols are best to use in the kets. For quantum computing, "1" and "0" might suffice and are well accepted. For the spin system, a more pictorial representation like a Bloch sphere (or circle) appears natural.

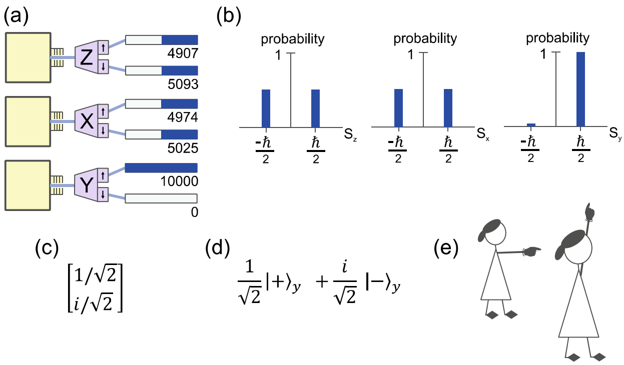

Fig. 2 Various representations used in the paradigms method. **a** sketch, **b** histograms, **c** matrix, **d** Dirac, **e** kinesthetic

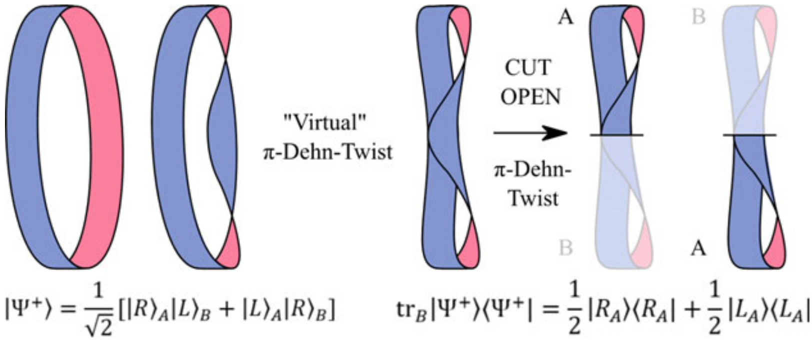

Fig. 3 A topological representation of entanglement. The belt represents entanglement. The twist and squeezing of the belt represent spatial separation. And a measurement is represented by cutting the belt in the middle creating two contrary twisted Mobius belts

4.3 Challenges and Opportunities

While it is known that learning quantum mechanics presents many challenges [36–38], it also presents many opportunities. One is certainly the opportunity to address the nature of science or epistemology of science in a meaningful way.

Looking from multiple perspectives, realizing that classical models do not adequately explain observations in the quantum world is fundamental in the learning of quantum theory. From the perspective of Posner's theory of conceptual change, this creates the necessary cognitive conflict. From more constructivist perspectives, like Knowledge in pieces, it provides the motivation for changing the classical resources of students or building new ones from scratch.

In learning quantum mechanics, there are multiple opportunities to design activities in which students predict the outcome of an experiment based on a classical hypothesis and are then forced to reject the hypothesis based on the outcome of the actual experiment (see for example [16]). These experiments can be done in multiple contexts in very similar ways.

4.4 Choice of Approach

The symposium revealed that the choice of approach is influenced by multiple factors. These factors are tentatively summarized in Table 2. The table shows what elements influence the choice of approach and what considerations are made in the choice as they emerged from the symposium.

Table 2 can help us sort specific approaches in view of the presented considerations. A major factor was observed to be beliefs about efficient conceptual change. The most radical representatives on this dimension appear to be the wave function approach and the quantum technology approach.

Table 2 Considerations that instructors make when choosing an approach as identified in the symposium

Element	Considerations
What do we want students to learn?	Wave function? Two states? Quantum technology? Quantum computing? Should they be able to calculate anything? Measurement? Indeterminism? Uncertainty principle? Nature of science? Philosophical implications? Tunnelling?
External constraints	Is there already an obligatory curriculum? Is the course preparatory for a specific purpose? How much time do we have? Can we change the format of the lectures? Do we have support for experiments or ICT?
Methodological aspects	Do we want lecture format? Do we want an active engagement course? What active engagement framework should we choose? Can students work in groups? Can they have homework?
Theoretical commitments	Do we want to make a connection with classical physics? Do we want to start from scratch? Do we want to build upon existing students' ideas?
Philosophical considerations	Do we want to emphasize the controversies? Do we want to emphasize the apparent paradoxes? Do we want to include the role of the scientific method in philosophy? Do we want to avoid any controversies and apparent paradoxes?

The wave function approach aims at the wave-like representation of particles and the related topics, especially the explanation of the double slit experiment and tunnelling. Useful representations are those of wave functions in potential wells such as provided by PhET [31] and Quantum composer [30]. The Dirac notation is not very suitable for this approach. By its nature, this approach cannot avoid students' prior knowledge (resources) on waves and potentials. Krijtenburg-Lewerissa showed that such approach benefits from deepening the understanding of relevant classical concepts. Among these are also special cases of classical waves [22]. However, depending on philosophical considerations, one may intentionally choose to include controversial and apparently paradoxical topics to incite interest in students, especially students who do not aim at becoming natural scientists and are more interested in the broader philosophical implications of the truthiness of quantum mechanics, such as does this tell us anything about fate and determinism. Krijtenburg-Lewerissa implied that this approach might necessitate changes in the teaching of other related topics in the curriculum. If not, additional time spent on these topics would be beneficial.

The quantum technology approach, on the other hand, starts from scratch with completely new concepts of qubits and quantum gates. These are completely new rules that do not present any relation to existing knowledge. If anything, they evoke resources about programming for those who possess them. Students can learn the new rules as they learn the rules of chess. There is no conflict with any existing knowledge. The simple representations with Dirac notation and quantum gates allows them to predict outcomes of a variety of experiments. Despite the "from scratch" approach, students in the post-test were able to respond to fundamental questions about the concepts of quantum mechanics, such as what does knowing a state imply and how would you respond to someone's particular statement on quantum mechanics.

A more nuanced example of how the considerations in Table 2 influence the choice of instructional method was given by Emigh [33]. He compared the *Paradigms* and *Tutorials* approaches to teaching quantum physics. Both courses commit to a social constructivist approach in which students should build their own knowledge for which interactions between students are crucially important. However, there are differences in the considerations about other topics. Emigh emphasized the structural differences (how the course is scheduled and taught) and considerations about students' resources (what is assumed that students would already know).

In terms of structure, the Paradigms approach requires an overhauling of the schedule. Multiple active engagement methods are used and the course is compacted into a few weeks. In terms of students' resources, the Paradigms approach does not assume what prior knowledge students have, instead it asks and responsively adapts to students' ideas. For example, in the Dirac representation of states, each term has a complex coefficient in front of it. Complex coefficients may present a difficult conceptual node. To test students' ideas about them, they are asked to indicate with their left arm the complex phase of the coefficients describing a particular state (see Fig. 2e). Pointing directly in front of them represents phase zero real number), pointing to the ceiling represents phase $\pi/2$ (imaginary number) and so on. The instructor can then observe the students and react to the ideas that emerge as they emerge.

The Tutorials approach can be adopted in a regular course with lectures and recitations, no scheduling changes required. Tutorials are typically used in recitation sessions. In terms of students' resources, tutorials rely on the assumption that some student responses are predictable. These responses are usually derived from open ended questions with pilot cohorts and then used to prompt discussions in the following cohorts. As an example, tutorials contain dialogue between fictional characters about a topic wherein ideas that have emerged in the pilot cohorts are expressed and students have to comment on the statements made by the fictional characters. In particular, they are asked to explain why a statement is incorrect. This forces them to explore the reasoning of the fictional character and thus compare and contrast their own reasoning with it. This a powerful learning tool encouraging reflection. This type of problem is not limited to tutorials. Bondani mentioned using dialogue or statements attributed to fictional characters in their pre- and post-tests.

4.5 Teacher Training

If we want to bring quantum to schools, teacher training is fundamental. In some countries, high school physics teachers are taught at physics departments and learn the basics of quantum physics like any other physics student. In some countries they are taught at educational departments. In this case, it may be that they have never encountered quantum physics beyond that which is already in the high school curriculum. In some cases, physics in high school is taught by teachers of biology, chemistry, mathematics or general natural sciences. These have probably not encountered quantum physics ever before.

Bondani presented an interesting approach to teacher training. A summer school was organized taking 4 days for 7 h per day which welcomed students and teachers alike. The course was based on quantum technology. In this course, teachers and students experienced the same learning path.

Emigh did not directly address high school teacher preparation, but did address the preparation of the university teaching team consisting of the instructor and graduate or undergraduate teaching assistants or learning assistants. The preparation for the Paradigms and for the Tutorials consists of having the team solve the same problems as the students do, followed by discussing not only the expected conceptual difficulties, but also the conversations that they as instructors want to have with the students. What would be productive and why. This is very in line with Bondani's idea of having teachers and students go through the same materials. With the addition of pedagogical considerations for teachers at a later stage [39, 40].

While teacher education courses are often linked to other courses at the universities, in-service training programs are more independent and focused on a specific topic. A few common elements emerged from comparison of the programs described by Bondani and Emigh. In both programs, teachers/instructors experience one coherent course in the role of students. They are able to explore the materials that are being used, especially simulations and experiments to gain familiarity with them. Then, they are able to discuss pedagogical considerations, like the reasons for particular activities and their goals with course designers. The next step for teachers, as described in [40] is to design their own course with the support of the program instructors.

5 Discussion

The importance of quantum physics for teaching in schools and universities and for reaching out to the general public, has recently gained a great deal of attention and relevance due to the rapid progress in quantum technologies and in the fundamental understanding of quantum physics.

Many teaching approaches of quantum physics exist, each with very different focus. In the symposium, some characteristics of each approach emerged, which enable us to somewhat classify the approaches along various considerations. Therefore, there is not a unique approach or set of tools to be recommended but rather we present a tentative set of considerations, which are intended to help arrive at the choice of approach and tools based on the answers to these considerations. All these approaches have to be re-examined in the light of increasing knowledge and insights into the nature of the quantum world and learning of quantum mechanics, they have to be modified or evaluated in the light of the new quantum technologies, and taking into account the recently often pursued approach with two state systems.

With regard to quantum technologies, there is a certain focus on attracting professionals who will potentially choose this professional field. But when we think about school, we also have to keep in mind the many students who will pursue other career paths. Therefore, above all, the question arises as to the relationship between general education in quantum physics and a pragmatic, career-oriented approach to quantum technologies. This emerges as a topic for further discussion within the community.

The Symposium highlighted basic considerations to teaching quantum physics. The contributions were selected to follow in some sense the logical path to developing a curriculum, starting with the expected prior knowledge of students, then discussing key concepts and visualisations and instructional considerations. To finish off with an example of a course that includes also teacher preparation.

Krijtenburg-Lewerissa gave the example of the Netherlands and discussed what can happen if quantum physics is newly introduced into the high school curriculum. She emphasises with research that the imprint of classical physics on students affects their learning of quantum physics. The very precise question and survey with an ecologically valid intervention gives insight that a coherence of classical and quantum curriculum might be helpful. The question is whether the gap can be reduced without blurring the difference. There are fundamental differences between the classical and quantum worlds. If we successfully reduce the gap between them, what should be the fundamental differences that remain and how should we best address them? The comparison and contrast between the approaches described by Krijtenburg-Lewerissa and Bondani raises the question of how to achieve coherence in a school curriculum. Should the transition between classical and quantum physics be smooth or should it be a disruption? What aligns better with the general goals of physics education as a whole?

Heusler focused on how to teach key concepts of quantum physics, especially superposition and entanglement, by visualisations of very different types. The very insightful visual aids making the mathematical structure tangible allow deep research and insight into new teaching methods. The Bloch-sphere representation is very versatile and natural for spin states, but it may create difficulties when describing polarization states and double well states. Polarization states may present a particular challenge given that “0” and “1” are represented by up and down on the Bloch sphere, but represent vertical and horizontal polarization in the physical system. Another challenge for the Bloch-sphere representation is how to adapt it for typewriting. Regular fonts do not possess characters representing angles. And drawing a circle for every ket becomes very tedious. All these representations might serve by their variety the overarching goal of using multiple representations in general education in quantum physics, mentioned before. The question is, how to embed these representations in a meaningful manner into a teaching path on the characteristics of quantum physics.

Heusler further argued that the motivation for teaching quantum physics might not be quantum physics itself, but rather the impact it might have on the society. He noted that the transistor had an enormous impact on society, yet we do not teach its operation. Likewise, quantum technologies might have a huge impact on society, but that might not require us to teach the basics of quantum mechanics.

Emigh addressed two concrete approaches to teaching quantum mechanics at introductory university level. It was inspiring to see how different theoretical commitments about learning influence the choice of teaching method. While both adopt active engagement of students, they do it in very different ways. It would be interesting to look more intensely into the learning success under these different conditions.

Bondani presented a summer-school curriculum and an impressive number of activities in the framework of quantum technologies. She argued that the characteristics superposition, entanglement and measurement are to be viewed as a resource to build upon. This could contribute to the demystification of quantum physics. Accordingly, the approach focuses on these concepts introducing the qubit and quantum logic gates and their physical realizations avoiding reference to controversial notions. These represent another set of representations that are particularly useful in the context of quantum technologies but may prove useful in other contexts, too. The sequence with which the line of quantum computing is followed in the outreach activities may represent one possible way into the future of teaching quantum physics. In addition, the activities are designed to include students and teachers alike which is an interesting approach to teacher training. However, it remains to be investigated whether this type of approach would be applicable on a larger scale. The connection with classical physics is still strong among some instructors to the point where some refuse to stop teaching the Bohr atomic model [41].

6 Conclusion

The symposium on teaching and learning quantum physics has been organized to bring together experts on the topic and structured to address an organic set of questions: what to teach, how to teach, what are the challenges and how to train teachers to teach it.

The symposium revealed that the answers to most of these questions depend on a set of considerations. These considerations emerged from the symposium and the discussion and we believe could be a step towards classifying the various approaches and thus helping teachers choose the approach based on their answers to these considerations.

One set of considerations relates to the commitments made by a particular teacher. Among these, one central consideration is: Should we look for coherence with classical physics or should we accept and embrace a complete disconnect? Another consideration is: should we use mathematical expressions, visualizations of wave functions or Dirac notation? This depends on whether we are looking for coherence or not. The wave function provides coherence with waves. Dirac notation is a disconnect since it is not used in classical physics. All participants strongly agree that using multiple representations is beneficial for learning.

A different set of considerations is about external limitations. How much time do we have? Can we restructure the course are we preparing for a particular goal (like an exam or a career in quantum technology)? All participants strongly support active engagement methods, but the specific strategy depends on how we can structure the course. Likewise, the choice of topics to teach depends on whether we are preparing future quantum engineers or educating the general public.

The set of considerations that emerged from the symposium might be a starting point for a more sophisticated set of considerations that would enable teachers to choose an appropriate approach based on their answers to these considerations.

It must never be forgotten that all this is not only about the people who will later work professionally with quantum technologies, but above all about those who are "spectators" but still want to understand these fascinating activities and assess their impact on society. As Wagenschein said, "Understanding the comprehensible that's a human right" [42].

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Strategies for Active Learning and Assessment of the Learning Processes

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Abstract Active Learning strategies are acknowledged to improve student understanding in many disciplinary fields. However, both the shift in learning objectives due to the use of these strategies and the recent need to implement active learning taking into account the requirements of mixed-mode teaching due to the SARS-CoV-2 pandemic pose the problem of developing and validating new assessment methods and techniques. In this paper, examples of active learning activities focused on developing critical reasoning skills, like modelling and argumentation, and of assessment tools and methods will be presented and discussed.

Keywords Active learning · Assessment

1 Introduction

Over the last several years, active learning methods and strategies have received considerable attention from the educational research community. Today, they are credited with improving student conceptual understanding in many fields, including physics (e.g., Georgiou and Sharma [1]; Sharma et al. [2]), and helping student develop attitudes toward scientific inquiry and higher-order thinking skills (e.g.,

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Asok et al. [3]; Malanog and Aliazas [4]; Limbach and Waugh [5]), like the ability to 'apply', 'analyze', 'evaluate' and 'create', and, more specifically for physics, the ability to build representations (i.e., models) of real-life situations.

As a consequence, active learning methods and strategies are commonly presented in the literature as a credible solution to the reported lack of efficacy of more traditional educative approaches [6] that are often based on a lecture format, focused on a one-way transmission from the teacher to the learner of principles, concepts, and facts. Research has shown that a possible cause of this lack of efficacy of traditional education can be identified in its decontextualized and abstract nature, which often underestimate the interdependence of situation and cognition. Conversely, the strongly contextualized nature of active learning situations can help students to see knowledge as a tool to front and dynamically solve problems, rather than seeing it as the final product of education [7].

It is worth noting that some remain skeptical about AL real efficacy, and see it as one more in a long line of educational fads [7]. Many also express doubts about what AL is and how it can be considered different from traditional education. Particularly, they claim that their teaching methods can already be considered "active", as homework assignments and, in many cases, laboratories are part of them. However, involving students in AL is more than simply performing tasks such as in-class or homework exercises. Research has shown that effective AL is always based on a broad range of pedagogical processes that emphasize the relevance of student ownership of the discipline and activation of high-level and critical thinking skills [8]. Particularly, real AL methodologies harness the benefits of curiosity-driven methods and research-based/problem-based/team-based/context related learning, thus stimulating a learning that is meaningful to the students.

We must also not forget that an important part of any educational process is evaluation, as it assesses the effectiveness of an educational experience. It is clear that, with learning objectives specifically related to active learning and focused on the development of skills and processes, and also with the shift in teaching modes we are seeing in these days due to the SARS-CoV-2 pandemic, the standard evaluation methods focusing only on content knowledge become inadequate and the approach to assessment needs to be revised.

Particularly, the mindset for assessment needs to change, moving from tests aimed to assess knowledge of concepts to assessment tools specifically designed to evaluate the entire learning process, also during its development. So, next to summative assessment, aimed at evaluating the student learning at the end of an instructional unit by comparing it against some standard or benchmark, the teacher must pay attention to formative assessment, i.e., the in-process evaluations of student comprehension, learning needs, and progress during a lesson, unit, or course. Such an approach to assessment has also shown a tremendous power in promoting learning, as found by Black and William in their meta-analysis [9]. An intentional use of formative assessment during the educational activities can promote learning improving student understanding of concepts and skill acquisition.

So, in order to find solution to the lack of efficacy of traditional educative approaches, the teacher should possibly involve students in active learning, and use assessment techniques able to review the entire learning process, determining the effectiveness of the active-learning approaches proposed to the students. In this sense, there have been large efforts invested in the development and validation of formative assessment tools adequate to active learning environments. A number of European projects has been dealing with these issues in the science field, mainly at the secondary level, such as ESTABLISH, Fibonacci, CHREACT or ASSIST-ME [10–14]. Other EU projects have also introduced active learning methodologies in graduate and post-graduate education [15].

In this paper we discuss the nature and/or implementation of some active learning methods and strategies and of the assessment of student learning, as resulting from the contributions to a Symposium organized by the GIREP Thematic Group on Active Learning Strategies. After a brief introduction to the general idea and the theoretical foundations of active learning, two examples of educational strategies that can promote active learning in different contexts, and two examples of application of assessment methods fitted to study the effectiveness of active learning experiences will be discussed.

2 Active Learning

The general idea of active learning is deeply rooted on the constructivist models of human learning, that led to the development of the theory of cognitive apprenticeship [16]. This theory holds that to foster learning effectively, the teacher should take into account the implicit processes involved in carrying out complex skills. Cognitive apprenticeships are designed, among other things, to bring these tacit processes into the open, where students can observe, enact, build representations of the world and practice them solving problems with help from the teacher. This approach is supported by Bandura's [17] theory of modelling, according to which the learner must be motivated to learn, must have access to and retain the information presented, and must be able to reproduce the desired skill accurately. Part of the effectiveness of the cognitive apprenticeship model comes from learning in context and is based on theories of situated cognition [18]. Cognitive researchers argue that cognitive apprenticeships are more effective when skills and concepts are taught in strict connection to their real-world context and situation. Learning and cognition are fundamentally situated.

It is worth noting that active learning methods and strategies are also credited with improving students' confidence in self-directed knowledge acquisition from their experiences, so helping them in developing a Growth Mindset (e.g., Dweck [19]). According to Dweck's idea, Growth Mindset students are generally aware of how their learning may happen, and they believe that extra focused effort and motivation may improve their capabilities [20] and allow them to acquire expert skills from experience. So, the Growth Mindset prepares the students to assume responsibility for knowledge acquisition. According to Ericsson [21], the process found to be most effective in acquiring expert skills from experience is known as

Deliberate Practice. This is a particular type of practice that is purposeful, systematic, and performed at progressively more challenging levels [22]. While regular practice might include mindless repetitions, deliberate practice requires focused attention and is conducted with the specific goal of improving performance. A fundamental aspect of this process is that the student can develop self-awareness of his/her points of strength and weakness. This also allows the teacher to help focus practice that can be repeated at different levels of difficulty to improve a skill that is found as weak by both him/her and the student him/herself. Emphasis on self-awareness in Deliberate Practice is likely to play a role in the effectiveness of the Growth Mindset [23], and, more generally, in the effectiveness of active learning methods.

3 Modelling as a Key Strategy in Active Learning

In the last decades, a considerable interest has been developed, in the science education community, in fostering model-based reasoning at all levels of schooling. Many research reports and projects, aimed at proposing innovation and reforming science education, recommended that the focus of science education should be shifted from facts to overarching themes and toward the increasing relevance of models in teaching and learning science (e.g., NRC [24]). The words ‘modelling approach’ have become an umbrella term, which covers different perspectives and include several different meanings concerning modelling activities.

Some well-known approaches to physics teaching focus on the process of constructing conceptual models and identify model building as a superordinate process [25, 26]. The introduction of modelling activities in physics courses contributes to various content areas and enables students to take responsibility of their learning, actively searching for similarities and differences among a wide range of phenomena.

The following description of modelling as an activity for developing both knowledge and skills is a summary of a more complete work already presented elsewhere [27]. The theory is based firmly on the cognitive science of reasoning and problem solving and the reader is referred to the original and the references therein for further information. Although developed primarily for use in higher education, there is no reason in principle why the method cannot be adopted for use at secondary level.

The main question is, “Why? Why incorporate modelling activities into your class?” Moreover, what do we mean by modelling? Modelling is an important physics skill in its own right. The ability both to construct and interpret a mathematical model of some aspect of the physical world is an essential tool of the physicist and a graduate might reasonably be expected to have developed some competence in modelling. Yet, physics education research has shown repeatedly over the years that many graduates can demonstrate facility in mathematics but still have a poor grasp of underlying concepts. In other words, students might be able to set down and solve mathematical equations, but they are not building a model.

Physics Education Research has identified numerous typical misconceptions. They are particularly common in mechanics, but occur in all areas of physics and emphasising mathematics at the expense of the physics not only fails to address such conceptual errors, but also, as students are not given chance to restructure their own knowledge, there is a significant chance of developing further misconceptions. A structured approach to modelling emphasises the connection between mathematics and physics and in so doing develops skills and enhances conceptual understanding.

As with any skill, development requires practice. Specifically, students need practice translating ideas in physics to mathematics and back again. They need practice in thinking qualitatively and critically and using qualitative arguments to build a compelling case. Arguing their case among peers is an excellent way or students to develop key transferable skills.

This, then, is the "Why". But what about the "How?" If modelling is to be taught systematically as a skill that students can practice and develop, a clear idea of the nature and structure of models and the cognitive processes involved is needed. A brief summary of some essential cognitive psychology is necessary to appreciate the methods involved in the author's approach to teaching modelling.

Historically, there have been two main competing ideas about how humans reason: the mental rules approach or the mental models approach. The mental rules approach posits that humans are possessed of an innate sense of logic, but the evidence from syllogistic tasks, of the form some X are Y, and conditional reasoning tasks, of the form, if p then q, is that humans are far from logical in their approach. Only the salient points are given here and the reader is referred to Sands [27] for a fuller discussion.

When presented with a statement of the form, if p then q, and asked to identify the combinations of p and q consistent with the statement, subjects will generally identify the combination of p and q together as correct and the combination of p but not q as incorrect. The combinations of not p and not q and not p but q, although correct, are often deemed irrelevant. The last combination in particular reveals the absence of logical thought. The statement, if p then q, implies only that if p exists then so must q, but says nothing about whether q can exist independently of p. That requires a bi-conditional, if, and only if, p then q so the fact that the combination of not p but q is consistent with the conditional statement but is not immediately recognised as such is strong evidence that recourse to logic is not the primary mechanism of reasoning.

That is not say that the use of logic does not occur. Clearly it does. Anyone who has ever reasoned through a physics problem will appreciate the value of logic and the exercise of elaborating "not p but q" as consistent with the conditional statement, if p then q, requires logic. It is the fact that logic is not the primary form of reasoning that is important. There is considerable evidence that we form mental models and reason through those and that means that before formulating a mathematical model, we will have formed one or more mental models as we have reasoned through a problem to understand it and develop a strategy for solving it.

Mental models are recognised as having three fundamental features: they represent what is common to a distinct set of possibilities and each of the previous conditions, such as not p but q, corresponds to a separate model; they are iconic, as far as is possible; and they represent what is true at the expense of what is false. This last point is especially important as it reduces the load on working memory, which for the present purposes can be regarded essentially as a limited capacity storage function of the brain.

It follows that if we reason through mental models, we also form mental models when we understand concepts and solve problems. In forming a mental model, we form a relationship between components cued by the problem statement, e.g., all, some, none, etc. for syllogistic reasoning, p and q for conditional reasoning, and for physics problems the objects and agents that together make up the system of interest. Those relationships may be built on existing relationships that embody our understanding of the concepts we draw on as we reason about the problem. As with syllogistic and conditional reasoning tasks, we will tend to analyse the problem more deeply only if cued to do so. There is a good chance that an experienced physicist will have developed the habit of reflecting on a problem, but students are likely to need to be encouraged to test their mental models rigorously against ALL possibilities. Failure to do so might mean that the models are incomplete and incorrect in some respects and developing the mathematics from such a starting point will lead to errors. Actively building physics models under guidance is an effective way not only to encourage these habits, but also to address both pre-existing and emerging conceptual difficulties.

Relationships are central to mental models and to the outcome of the modelling process. Sands [27] has argued that these relationships are what are commonly referred to as concepts in physics and that a model is a causal or explanatory mechanism built on one or more qualitative relationships, or concepts, that leads to one or more new relationships or concepts. It will be evident from the above that building a mathematical model doesn't start with the mathematics, but with the physics. The initial equations come directly from an assessment of the physics of the problem and should therefore reflect the physics. The assessment stage is therefore an essential, but often neglected part of the modelling process. There are three stages in total in the modelling process developed by Sands and Fig. 1 shows a schematic of them. Called ACME, the stages comprise: assess, construct the model and evaluate. Figure 1a emphasises the connection between physics and mathematics domains and Fig. 1b shows that although the process is described as linear, it is in fact a cyclic process, with some form of evaluation occurring after every stage.

The evaluation is the element of the modelling process that tends to cause students most difficulty. It is essentially about checking whether the model makes sense and there are a number of important criteria that must be met. If nothing else, the evaluation should confirm these. First and foremost, the outcome of a model should be consistent with the initial assumptions. If it isn't, identifying the flaw can require drawing on physics from a wide range of diverse areas. The problem could lie within hidden assumptions or a failure of the mathematics to reflect the physics. Identifying the problem can take time and effort, but above all requires critical, open-minded thought aided by guided inquiry and discussion with peers.

It will be apparent from the preceding that modelling activities are best conducted in groups in order to stimulate critical thought through discussion with peers. Four

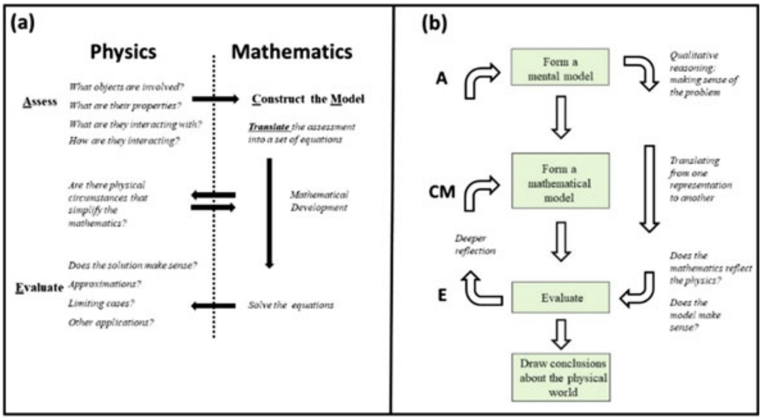


Fig. 1 Schematic of the ACME process showing contribution of each stage to the whole process (**a**) as well as the cyclic nature of the modelling process (**b**)

students per group is effective, but if the problem is relatively easy working in pairs might be sufficient. As for the assessment, it was found that assessing the process rather than the final outcome is the most effective. In particular, assessing the use of representations and the translation between them from one stage to another is especially important. Although the problems might be discussed in groups and models built collectively, an assessment of an individual's understanding of both the process and the model is possible using information set out according to the ACME protocol as identified in Fig. 1.

By way of summary, a model has been defined as a causal or explanatory mechanism that leads to the development of new concepts. A process for constructing models, known as ACME, has been developed and comprises three stages: Assess, Construct the Model and Evaluate. Each stage is important in the construction of a model, but the assessment stage is often either overlooked or underplayed in much physics instruction. During this stage, students will form and access mental models as they seek to understand the problem. Mental models tend to be qualitative and parsimonious and need to be fleshed out and checked for consistency. Modelling activities are best conducted through guided inquiry in teams and the process, rather than the correctness of the model, is a better focus for the assessment of student attainment.

4 Real Remote Laboratory to Actively Involve Students in Remote Learning Activities

The SARS-CoV-2 pandemic crisis has suddenly required a shift of learning activities in remote mode, challenging the effectiveness of distance learning methodologies [28] especially in contexts where laboratorial activities play a central role. During the pandemic emergencies, virtual laboratory (VL) experiments have been substituted for the real experiments [29, 30]. However, real laboratory (RL) experiments, made with easily available materials and self-prepared by learners at home, are preferable, especially in didactic setups based on laboratorial inquiry methodologies [31, 32]. That said, the conventional RL is not always available, and in such cases, a possible substitute could be the “real remote laboratory” (RRL), where students run real experiments by remotely accessing experimental apparatuses [33, 34].

In this context, responding to specific training requests by local schools in Calabria (southern Italy), in the academic year 2020/21 an innovative Real Remote Laboratory (RRL) initiative was designed and implemented, within the Italian national program (PCTO) aimed at fostering the transversal skills of high school students and at developing their specific knowledge and skills useful for adequately choosing the post-secondary training path. Since a distinctive feature of the PCTO program is to offer students the opportunity to participate in educational activities within a real working context, the learning path was framed in the research activities context of the Laboratory of Applied Physics for Cultural Heritage at the University of Calabria, with particular reference to spectroscopic and colorimetric techniques applied to the conservative diagnostic of fine arts [35].

RRLs proposed in the literature (e.g., Gröber et al. [33, 34]) are very well-designed and useful, but require a considerable technical infrastructure, including some kind of physical control interface for apparatuses available in university laboratories, and a specific software user interface to remotely access such apparatuses. This means that such a kind of RRL cannot be set up extemporaneously for a quick response to specific distance learning needs, as it happened at the beginning of the SARS-CoV-2 pandemic. To address these limitations, a different paradigm of RRL was planned and tested, and structured as follows: (i) students were introduced to the problem and an inquiry-oriented experimental strategy was outlined; (ii) a human instructor executed the real experiments in the laboratory, while students were participating in video streaming at home; (iii) the experimentally acquired raw data were transmitted to students, who (iv) processed them; if necessary, they asked the instructor to do additional measurements in a subsequent real time session. Finally (v) information obtained from data processing were cooperatively discussed and conclusions were drawn. The learning activities were enriched by elements of web-mediated real time interactions, on the model of Interactive Lecture Demonstrations [36], where all interactions among players (single students, university instructor, school tutors) were performed in video conference mode.

The learning path was contextualized on the physics of colour, its digital representation and processing, with particular reference to the modeling through colour

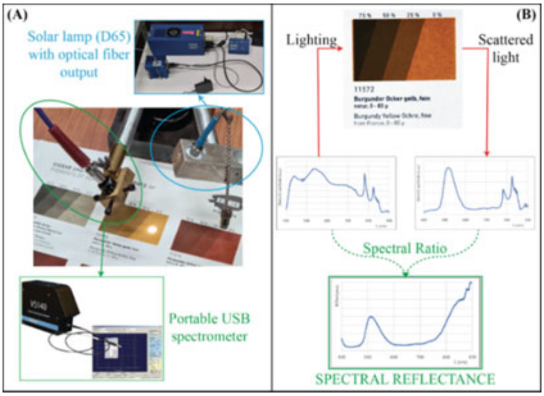


Fig. 2 **a** Snapshots from the real laboratory: details of the solar lamp with optical fibre output (top), and portable USB spectrometer (bottom). **b** The pigment sample is illuminated by the solar lamp (D65-like spectrum, previously determined), the scattered light from the sample is collected through the optical fibre and analysed by means of the spectrometer; finally, the normalized ratio between the two spectra is determined

spaces, as the RGB model [37]. The real experimental activities were focused on various reflectance spectroscopy measurements on standard pictorial pigments, in order to investigate the relationship between perceived colour and spectral shape of the reflected light (Fig. 2). Moreover, the false-colour processing method [38] was introduced to characterize pigments, discriminating between like-appearing colours corresponding to different spectral composition (metamerism).

Considering the orientation purpose covered by the learning activity within the context of PCTO Italian project, our learning activities were planned to familiarize students with the research activities context of the laboratory of Applied Physics for Cultural Heritage, and in particular with some specific skills fundamental for a researcher in this branch of physics, like production and interpretation of experimental graphical representations (Fig. 3). In this context, particular attention was devoted to the assessment-related issues. The assessment was performed during the learning path and at the end of it, in order to evaluate both the learning process and its outcomes. Students were asked to produce technical reports in small groups on different topics (as for example on the false colour processing methods, or on the characterization of pigments by spectral reflectance) and to discuss their reports in plenary sessions. The peculiarity of the proposed learning path requires specific evaluation and assessment methods, considering both real and virtual nature of lab activities and the purely virtual nature of the interaction among learners and between them and teacher. In this perspective, we designed a kind of assessment (appropriate for distance learning with particular reference to RRL) with the aim of providing students with suitable vocational feedback, in order to help them orientate for post-secondary instruction. The main idea was to plan an appropriate assessment for a non-supervised learning context (such as distance learning) that gives students feedback related to technical-scientific research context. In this perspective, we planned

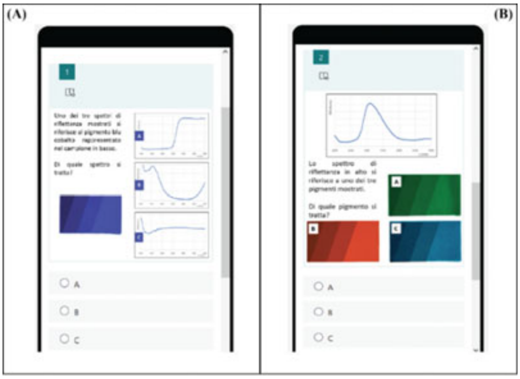


Fig. 3 Two examples of formative quizzes concerning the matching between spectra and perceived colours, contextualized on experiments done: **a** multiple choice question about the cobalt blue pigment (A left) and the corresponding reflectance spectrum (A, B or C, on the right); **b** multiple choice question about the reflectance spectrum illustrated on the top and the corresponding pigment (A, B or C)

a set of real-time "formative" assessments in order (a) to foster students' attention and participation by means of common use tools (like smartphone, Fig. 3) and (b) to give them orientation feedback through live discussion of results.

5 Formative Assessment of Inquiry Learning in Science

Among the active learning methods, Inquiry-Based Learning (IBL) has been one of the most advocated in science education over the last two decades [39]. It leads to knowledge and understanding of the world by asking inquiry questions, formulating hypotheses, and testing them by collecting data during scientific experiments and using them as evidence to explain phenomena or events. In general, learning by inquiry follows an investigation cycle the researchers employ when they study a scientific problem. As we have seen in Sect. 2, the concept of this pedagogy is not new; however, its educational potential has been increasing in technology-based societies [40]. It has been associated with increased students' motivation and interest in science, supporting the development of inquiry competencies and conceptual understanding [41]. Constant engagement with new open-ended problems and situations experienced in the IBL stimulates also students' curiosity and their self-learning abilities, which are particularly important regarding the positive attitudes and skills for life-long learning.

As in any other learning environments and teaching/learning strategies, assessment in IBL environment involves a collection of data, its analysis, formulation of conclusions and feedback given to the students. Formative or summative characteristics of evaluation is determined not by data itself, but by the use of data [40].

Formative assessment (also called 'assessment for learning' [42]) serves the improvement of the learning process and is linked to the instant feedback given to students during this process. It can become relatively informal through on-the-fly interactions (informal formative assessment conversations [43]) or can be implemented more formally—with the help of evaluation tools and assessment plans prepared in advance (e.g., rubrics [44]). However, if used in the IBL approach, it should also reflect the goals and nature of this pedagogy (e.g., use of reasoning tests [45], tests taken collaboratively [46], etc.).

During the SAILS EU project [11], 19 science learning units in the IBL pedagogy were designed together with many ready-to-use assessment tools embedded into the material. More than 2500 teachers in 12 countries participated in SAILS teacher education programs with the IBL practical training based on the developed material. Each unit was implemented by 3–8 teachers and reported as case studies. The assessment focused on a particular set of inquiry skills and competencies in every learning unit was proposed and associated with recommended evaluation tools. Brainstorming and classroom dialogue were assessed using checkboxes (Electricity unit) and less formally (on-the-fly) in most other units. In half of the units, teachers implemented self- and peer-assessment tools for the evaluation of collaborative work in the classroom. Worksheets and other student-devised material were evaluated with rubrics in almost all cases. In one-third of case studies, teachers collected their assessment data in observations.

Most of the teachers followed the units and assessment strategies proposed in the ready-to-use materials, and a few of them willingly adapted units or assessment tools to their purposes. In general, the frequency of implementation of the assessment methods spoke for teachers' preferences. A closer look (e.g., Electricity unit) into case studies revealed that some of them felt uncomfortable with the evaluation tools the others reported as favourable.

So, when designing teaching materials user-friendly and beneficial for as many classes as possible, a broad spectrum of assessment opportunities should be included, both for formative and summative evaluation of the IBL approach. At the same time, pre-service teacher education and CPD programs should put more emphasis on practical activities on the development of teachers' skills in designing assessment strategies and tools.

6 Implementation of Active Learning Strategies Enhanced by Formative Assessment Tools

As we said previously, a number of European projects [10–14] dealt with the issues related to assessment of active learning environments, emphasizing the role of formative assessment tools in the evaluation of the effectiveness of the educational experiences. These projects motivated project partners to continue in these efforts at national levels. In Slovakia, the large national project IT Academy has been running in 2016–2022 [47]. The main projects goals emerged from the imbalance between the current goals of the curriculum emphasizing IBSE and active learning strategies and lack of instructional materials. As a result, one of the main goals is to support science, mathematics and computer science education by developing teaching and learning materials based on the active learning and inquiry-based learning approaches enhanced by digital technologies and formative assessment tools (Fig. 4).

In order to achieve the main project goals, design-based research has been implemented. A number of experts in the field of physics education designed teaching and learning materials respecting the agreed criteria. Each lesson has been designed at a certain level of inquiry following the framework in Table 1 adapted from Banchi and Bell [48] and starting with a driving question. The lesson plan follows the well-known 5E learning cycle [49] and is complemented with formative assessment tools. The materials were implemented in the classroom in two subsequent cycles (Fig. 5). In each round the lesson plan was implemented and reviewed by at least five teachers. Teachers' feedback was collected with the help of a questionnaire leading to the updated version that was again implemented into teaching. The second trialling resulted in the final version of the materials that are presented online for a wide use of teachers and students.

In physics, 80 lesson plans for upper and 78 lesson plans for lower secondary schools have been developed with materials for teachers and students (worksheets, exemplary filled-in worksheets for teachers, computer files, and other complementary materials). The important element of the lesson plan was the use of formative assessment tools. In the following we present examples of activities grouped on the basis of the specific formative assessment tool.

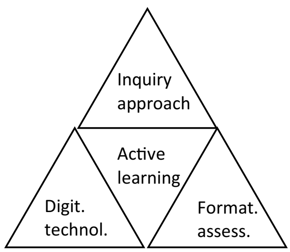


Fig. 4 Main principles of teaching and learning materials

Table 1 The five levels of inquiry (what students are provided with is marked x)

Level of inquiry	Problem/question	Procedure/method	Result	Student independence
Interactive demonstration/ discussion	x	x	x	
Confirmation inquiry	x	x	x	
Guided inquiry	x	x		
Bounded inquiry	x			
Open inquiry				

Fig. 5 Two-round teacher and learning materials' classroom implementation

6.1 Making Predictions as a Natural Part of the Inquiry Activities

The Predict—observe—explain (POE) strategy was used almost in every activity to predict the outcomes of an experiment. Predictions are compared with the experimental results and students' explanations are asked and explored in order to uncover students' ideas. The activity on confirmation of the law of momentum conservation is based on collisions of carts on a frictionless track. Students predict the velocity and momentum graph (Table 2). The activity on determining the work done by, and power of, a weightlifter is based on the video-measurement of the bar position with students' predictions of position graph (Table 3).

6.2 Peer Assessment in Project-Based Learning

Another activity was designed as project work, with students working in groups on the assigned research problems. At the end they handed in the project report with detailed description of the project goals, experimental design, data collection, their analysis and interpretation and conclusions. After that each group was assigned to review projects from two other groups, completing an evaluation report for each group. These evaluation reports were presented to the whole class at the same time as the group project, which led to an interesting discussion between the authors and reviewers. The project reports as well as the evaluation sheets were also commented on by the teacher, who summarized all the results in front of the whole class. The

Table 2 Students' predictions on the law of momentum conservation demonstration

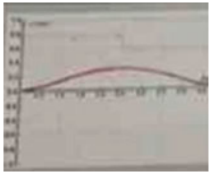
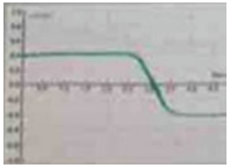
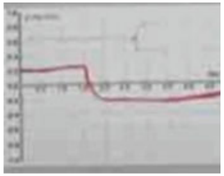
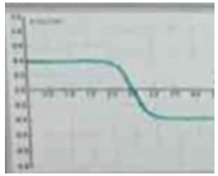
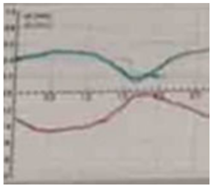
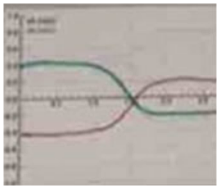
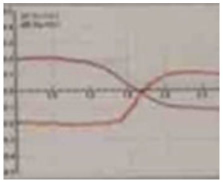
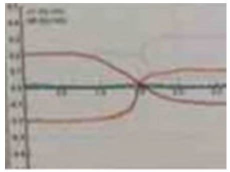
Cart moving from and to the motion sensor			
Prediction	Result	Prediction	Result
Velocity graph	Velocity graph	Momentum graph	Momentum graph
			
Two carts moving with the same mass and speed towards each other collide and bounce apart			
Prediction	Result	Prediction	Result
Velocity graph	Velocity graph	Momentum graph	Momentum graph
			

Table 3 Student's prediction on the bar motion during the weightlifting in the squat snatch

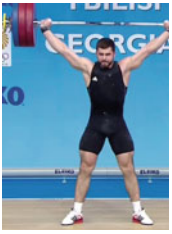
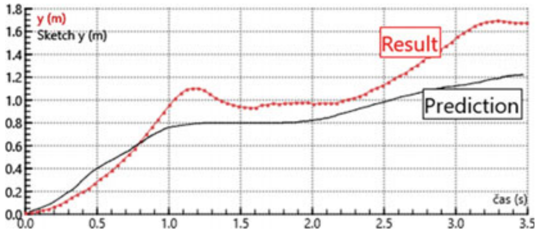
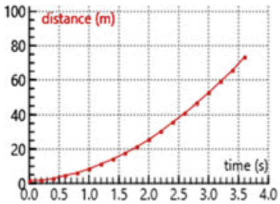
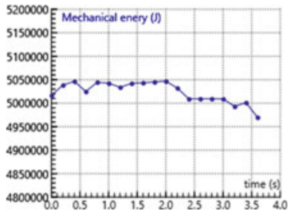
Prediction/result of the position graph	
	

Table 4 Results of the project group work with example of reviewers' comments

Research question: In the video you can see a giant drop from the tower of horror. How does the cart move? Is the cart in free fall?		
		
The report does not include any detailed measurement procedure The distance-time graph is not fitted correctly. They did not show if this motion is uniformly accelerated or not or if it is a free fall. The kinetic energy is not calculated properly. The results do not confirm law of mechanical conservation and this is not explained		

implementation shows that students are not skilled in peer assessment and we need to help them by creating situations where they are expected to express their opinion on someone else work supported by reasonable arguments. The example of a project with a sample of quite critical reviewer's comments is given in Table 4.

6.3 *Exit Card 3–2–1 as a Metacognitive Formative Assessment Strategy*

The following activity was aimed at the concept of resonance. Students were analyzing a number of pre-recorded experimental data of displacement of a spring-magnet oscillator influenced by a driving force generated by an alternating current-carrying coil surrounding the mass of the oscillator. Different groups were analyzing the same oscillator with driving force of different frequencies to determine the oscillator frequency in a steady state and its amplitude resulting in a graph of the amplitude

Table 5 Example of exit card on the phenomenon of resonance

Write after the lesson	Answers
3 Things I've learnt	1. Resonance phenomena have caused a number of disasters—for example, the collapse of several bridges, and therefore soldiers must not march on bridges, because regular impacts on the bridge can cause resonance 2. When playing music loudly in a room, the furniture or walls of the room may vibrate if the natural frequency of these bodies equals the frequency of the sound 3. Resonance occurs even in the microwave, when the frequency of microwave radiation resonates with the natural frequency of the oscillating motion of water molecules that are in the food
2 Interesting facts that interested me the most	1. An interesting fact is that a bridge was built in Tacoma in 1938, which collapsed in 1940 due to resonance phenomena—massive oscillations occurred, which were faster and faster, until it collapsed about 11:10 when oscillations ended and the bridge collapsed 2. The glass can be broken by sound as long as the frequency of the sung tone equals the frequency of the glass' own oscillations
1 Question that I still have	Despite the physical explanation, I still have one question, how is it possible to break the glass by the tone created by the voice? Because I've never seen anyone with my own eyes who can do it

vs. frequency of the periodic driving force (resonance curve). These results were used to explain concrete examples where resonance plays an important role. At the end of the lesson the 3–2-1 exit card was used. The example of a student's response is in Table 5.

6.4 *Self-Assessment as a Strategy to Reflect on a Student's Own Learning*

Many activities are accompanied by self-evaluation sheets that make students to think about their own learning and how they understand the concepts and skills. At the same time, it provides feedback to the teacher. In the activity on Faraday's law of electromagnetic induction, students investigate the voltage induced in a coil situated between the poles of a turning horseshoe magnet. They analyze the experimental results for different frequencies of turning magnet and different numbers of coil turns to deepen the conceptual understanding of what the induced voltage depends on (Fig. 6).

When implementing self-assessment strategies, students often cannot assess their achievements objectively. It may be caused by fear from teacher's evaluation. Therefore, students need to be involved in self-assessment regularly in order to develop self-assessment skills and understand that based on their feedback a teacher can improve teaching for their benefit (Table 6).

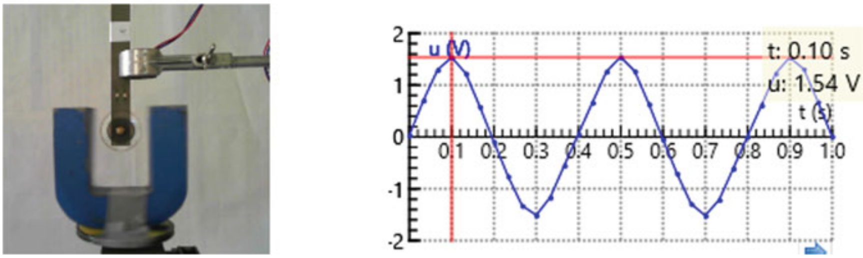


Fig. 6 Turning magnet with a coil. The red cross corresponds to the position of the magnet in the picture on the left

Table 6 Example of self-assessment sheet

EVALUATE YOUR OWN LEARNING				
After the activity, I am able to …		With big assistance	With assistance	Independently
Faraday's law	Write down the law mathematically			x
	Explain the physical meaning of the law			x
Analyze relationship between the time dependence of induced voltage u(t) and magnetic flux $\Phi(t)$			x	
Explain what parameters influence the amplitude of induced voltage U_m			x	
Draw the induced voltage–time graph u(t) on the basis of the magnetic flux-time graph $\Phi(t)$			x	
Solve simple problems connected with the law			x	

7 Discussion and Final Remarks

There is today a wide consensus that to improve student learning the traditional lecture format, where students passively receive information from the teacher, should be evolved towards an approach promoting specific student engagement and activity in learning. In the active learning approach students do more than just listen to a lesson. They are engaged in actively posing and discussing questions, reading, writing, collecting data from different sources, constructing and discussing models and solving problems aimed at developing their knowledge, skills and attitudes. In active learning, students are involved "in doing things and thinking about the things they are doing".

Active learning methods and strategies are credited with improving student conceptual understanding in many fields, including physics. Research has shown that improvement arises from the strongly contextualized nature of education that active learning brings, that focuses on the interdependence of situation and cognition. When learning and context are put together, knowledge is seen by learners as a tool to be used dynamically to solve problems and to develop critical transversal skills, rather than seeing knowledge as the final product of education. For these reasons active learning has gained strong support from teachers and faculties looking for effective alternatives to traditional teaching methods.

In this paper we briefly discussed the nature and/or implementation of some active learning methods and of strategies. We have seen that close attention should be deserved to aspects like the development, during didactic activities in the classroom, of superordinate cognitive processes, like modelling. These can be fostered by encouraging students to test their reasoning ways rigorously against several possibilities, and systematically reflect on all the aspects of a problem, performing at progressively more challenging levels. Moreover, the SARS-CoV-2 pandemic crisis has clearly shown that distance learning methodologies must evolve toward a better engagement of students in activities where they can actively participate in their learning. An example of the evolution of pedagogical laboratory activities, so important in experimental disciplines like physics, is an accurate implementation of Real Remote Laboratory, that aims to involve students in the analysis of data collected by the teacher in video streaming, in possibly requiring the teacher to collect more data to improve the analysis, in discussing and contrasting the results obtained by each student/group of students and drawing conclusions about the cooperative work performed.

However, simply planning and developing innovative educational experiences based on an active role of the students in their learning is not the end of the story. It is equally important to assess the effectiveness of the learning experiences, even just to find possible points of strength and weakness, re-shape and improve the experiences. The substantial differences between the objectives specifically related to active learning and the ones related to more traditional learning clearly ask the researchers and the teachers to rethink the assessment methods, in order to adapt them to the new learning environments based on active engagement of students in their cognitive processes. The last two sections of this paper briefly discussed some examples of planning and implementation of formative assessment methods for active learning environments. It can be argued that formative assessment can greatly improve the learning process, as it is often linked to the instant feedback given to students during this process and can be performed in a specific context and pedagogical situation, according to the ideas of cognitive apprenticeship. However, there is still space for researchers to perfect assessment techniques to be used, for example, in distance learning environments designed to promote student active learning. Moreover, teachers need training in the field of formative assessment strategies to fully understand their purpose and how to adjust teaching based on their implementation.

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Selected Oral Presentations

Enhancing Second-Level Physics Students' Energy Literacy

Eilish McLoughlin and Suzan Gunbay

Abstract This study discusses the design and implementation of a pedagogical approach for enhancing second level students' energy literacy. This study has been carried out as part of the Energising Education to Reduce Greenhouse Gas Emissions (ENERGE) project. This approach has been used to co-design teaching and learning materials for use in second-level schools across six Northwest European regions: France, Germany, Luxembourg, Ireland, the Netherlands, and the United Kingdom. The approach has been informed by both educational practices and literature and identifies learning outcomes for energy literacy across three domains: cognitive, affective, and behavioural. Feedback from teachers that have used this pedagogical approach and materials in their physics classroom have reported on the benefits of this approach to developing student's energy literacy.

Keywords Energy literacy · Pedagogical approach · Physics education

1 Introduction

With the ageing of the existing school building stock (new schools and deep retrofits can take years from planning to completion) there is a need for low-cost solutions that enable long-term resource efficiency in schools and reduced greenhouse gas emission (GHG). The Energising Education to Reduce Greenhouse Gas Emissions (ENERGE) project (2019–2023) addresses this need using targeted technical and educational interventions that include the design and implementation of new pedagogical approaches to promote energy saving and awareness at school by mobilising whole school communities. ENERGE partners with schools across six North West

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European (NWE) regions: France, Germany, Luxembourg, Ireland, the Netherlands, and the United Kingdom [1].

At second level, the topic of energy is generally taught as a cross-cutting concept in science, and students build their knowledge about energy around four central ideas: energy transfer, transformations, dissipation, and conservation [2, 3]. The concept of energy literacy highlights the importance of teaching and learning about energy within a wider context of systems which incorporate environmental, social, political, technological, and economical dimensions of energy-related topics [4–8]. Energy literacy is important because it promotes conscious citizens, who have a positive and proactive attitude towards accepting and adopting these necessary measures [9].

In 2008, DeWaters and Powers proposed a set of characteristics for evaluating student's energy literacy across three domains: cognitive, affective, and behavioural [4]. DeWaters and Powers' model offers a framework for designing learning opportunities to develop energy literacy and deepen scientific knowledge about energy as well as promoting learners to make decisions, solve problems and take action [9]. This model has been adopted by other scholars to develop and assess student energy literacy in second level education [10–12]. With the aim of enhancing the energy literacy of second level students in the six NWE regions, the objectives of this study are to:

- Develop a pedagogical approach to enhance second-level students energy literacy.
- Design energy teaching and learning materials that align with the existing curricula.
- Improve students' engagement with GHG reduction strategies at school.

2 Methodology

The process used to design and develop the ENERGE Units and activities was carried out over three stages, as shown in Table 1. The process was collaborative with teachers and researchers forming the ENERGE Teachers' Network to facilitate interregional collaboration across the NEW regions. The network comprised of 22 teachers and 13 project partners. The Network met every two to three months during 2020–2021 to share, review and discuss teaching and learning materials related to energy and relevance to curricula in each region.

Stage 1 explored opportunities for ENERGE by comparing existing education models in the six countries to identify curricula/subject areas where energy, carbon emissions and energy efficiency topics were present. This information was collated through desk research carried out using the Eurydice resource [17] and a questionnaire that was completed by teachers in the ENERGE Network. A review of literature was carried out to identify the types of knowledge, skills, attitudes, values, beliefs, and behaviours were associated with energy literacy at second level. The review was conducted using the Web of Science (WOS) database. The review process included planning, conducting the searches, analysis and interpretation of the results and reporting. A full summary of this process can be found in Tables 2 and 3.

Table 1 Methodology for developing ENERGE teaching and learning activities

Stage 1	• Comparison of National Education Models • Review of Literature 2010–2020	ENERGE teacher network meetings
Stage 2	• Collation of activities/resources from other projects • ENERGE Teacher Network Workshops	
Stage 3	• Piloting of units and activities by teachers • Oral/written feedback on piloting • Review and updates to ENERGE materials	

Table 2 Literature review process

Steps taken	Description
Planning	Formulation of research questions, planning of search and screening strategies, development of inclusion criteria
Conducting the search	WOS database search, title and abstract screening, classification of articles, coding, and mapping articles with relevant research questions
Analysis and interpretation	Qualitative analysis of selected studies under each research question
Reporting	Presentation and discussion of results with respect to the research questions under study

Table 3 Criterion used for selecting publications

Aspect	Criterion
Publication type	Peer-reviewed publications (journal articles only)
Language	English
Timespan	2010–2020
Relevance	Post-primary
Age-group	12–19 years old
Location	Any
Research method	Qualitative, quantitative and mixed

The following research questions were used to guide the review process:

1. How is 'energy education' currently incorporated into second-level school curricula?
2. How is energy literacy defined in the literature and why is it important for society?
3. What knowledge, skills, attitudes, or values are associated with developing energy literacy?
4. What models are used to conceptualise energy and develop energy literacy at school?
5. What pedagogies are associated with developing energy literacy/energy education at school?

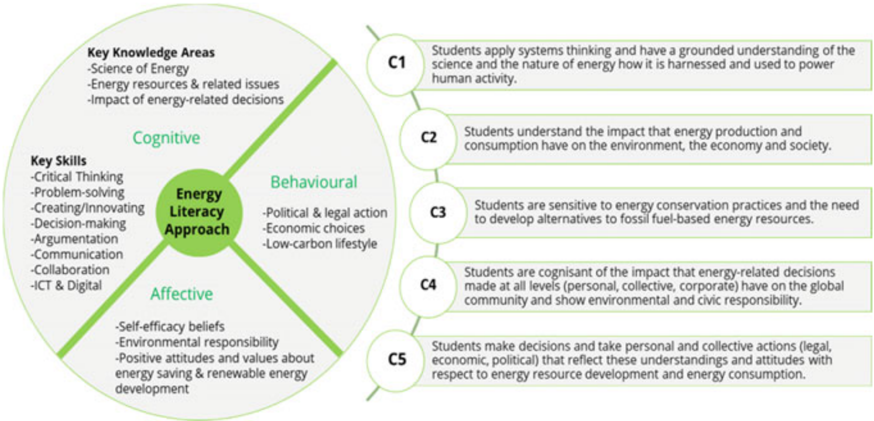

Fig. 1 ENERGE Pedagogical Approach adapted from DeWaters and Powers [4, 9]

Stage 2 involved designing ENERGE Units and activities that could be adopted for use in the existing curricula in the six countries. A collection of 46 energy teaching and learning activities (ENERGE activities) presented over nine units were developed by the authors engaged in a process of co-design with 22 s-level teachers (including physics teachers) working in ENERGE project schools in these six countries. Each activity was mapped to the five energy literacy characteristics described by DeWaters and Powers [3] (see Fig. 1). During the co-design process, written feedback on the ENERGE pedagogical approach and the five energy literacy characteristics was collected from participating teachers. Teachers were asked to provide response on the following questions:

1. To what extent are energy literacy characteristics embedded in your subject curriculum?
2. How can the development of energy literacy characteristics support student learning in your subject?
3. What could be done to improve the teaching of the above characteristics within the curriculum?

Stage 3 involved a collaboration with participating teachers to pilot the developed units and activities with their second level students. Oral and written feedback on the ENERGE pedagogical approach, the implementation of units and activities in the classroom and teachers' reflections on student learning were collected from two physics teachers in Luxembourg.

3 Findings

3.1 Literature Review

A review of literature identified 112 articles relating to energy literacy and the key findings for each question are presented.

How is 'energy education' currently incorporated into second-level school curricula? Energy concepts are included widely in STEM education and under-represented in non-STEM subjects except for science, technology, society, and environment education (STSE) and STEAM oriented curricula that link energy science with technological, environmental, sociological, and economic considerations [5–8]. Energy should be treated as a cross-cutting concept that is centred around four interdisciplinary conceptualisations of energy namely that it exists in forms, can be transformed, transferred, dissipates, or degrades and is always conserved [2, 3]. Learning progressions for energy that are centred around the four ideas can help to mitigate misconceptions, foster interdisciplinary knowledge building which is important for relating energy to systems and to real-world energy-related issues and crises [2, 5, 6].

How is energy literacy defined in the literature and why is it important for society? Energy literacy is defined broadly as the ability to demonstrate a sound understanding of scientific and practical energy-related knowledge, positive energy attitudes and values as well as someone who can make informed decisions about energy and strives to take actions that reflect these attitudes. It is generally agreed that energy literacy models have outcomes for learning that are cognitive, affective, and behavioural [9–12].

What knowledge, skills, attitudes, or values are associated with developing energy literacy? Effective energy education is associated with at least three types of knowledge (1) energy science and systems (2) energy resources and associated issues and (3) the effect of energy-related decisions at all levels and at least 9 specific skills and competences: namely metacognitive skills such as critical thinking, reasoning, problem solving [14] as well as innovation, design or creativity, decision making, data analysis, numeracy [7, 11] argumentation, communication [15], collaboration [16] and digital competency and ICT skills [11]. The attitudes, values, beliefs, and behaviours associated with being energy literate include a positive attitude towards renewable energy and the reduction of GHG emissions, feelings or belief in self-efficacy, environmental responsibility, willingness to adopt a low-carbon lifestyle the ability to make informed decisions about energy and a willingness to act and participate in the civic process [7–10, 12].

What models are used to conceptualise energy and develop energy literacy at school? In 2008, DeWaters and Powers proposed a set of characteristics for evaluating student's energy literacy across three domains: cognitive, affective, and behavioural [4]. DeWaters and Powers' model offers a framework for designing learning opportunities to develop energy literacy and deepen scientific knowledge about energy as well as promoting learners to make decisions, solve problems and take action

Table 4 Characteristics of an energy literate student [4, 9]

An energy literate student
• has a basic understanding of how energy is used in everyday life
• understands the impacts that energy production and consumption have on all spheres of environment and society;
• cognizant of the impacts of individual, collective, and corporate energy-related decisions, and actions on the global community;
• is aware of the need for energy conservation and the need to develop alternatives to fossil fuel-based energy resources; and
• strives to make choices, decisions, and take actions that reflect these understandings and attitudes with respect to energy resource development and energy consumption and is equipped with the necessary skills to do so

[9]. DeWaters and Powers model, as summarised in Table 4. This model has been adopted by other scholars to develop and assess student energy literacy in second level education [10–12].

What pedagogies are associated with developing energy literacy/energy education at school? Student-centred and active pedagogical approaches that are experiential and adopt a hands-on learning approach have been found to be effective in the acquisition of energy literacy. These include problem [14], and inquiry-based learning [5, 11], design engineering [14], community-based learning [6, 14] and digital gamification [10, 11].

3.2 Pedagogical Approach

The pedagogical approach adopted in this study identified student outcomes for energy literacy in the cognitive, affective, and behavioural domain (shown in Fig. 1). The approach outlines five energy literacy characteristics (C1-C5) and expands on those presented by DeWaters and Powers in their energy literacy model [4, 9]. The approach was used to design a collection of 9 units comprising 49 teaching and learning activities that address these characteristics addressing personal, local, and societal energy efficiency and awareness (outlined in Table 5). All the units and activities developed are available to download online [13]. Each unit has been designed to address each component of the approach outlined in Fig. 1. and all the five Energy Literacy characteristics (C1-C5).

The pedagogical approaches that were incorporated into the development of the ENERGE modules and units were also informed by the literature and include activities that use Scientific Inquiry, Problem-based Learning [14], Engineering Design Learning [14], Gamification and Digital Learning [10, 11] and Community service and Action Projects [14]. The modules are currently being adopted for use in second level curricula (including physics) in the six NWE countries that make up the ENERGE project.

Table 5 Overview of ENERGE modules (teaching and learning activities)

Module	Unit	Number of activities
1. Being energy efficient	1. My energy diary	7 activities
	2. My energy footprint	6 activities
2. Designing energy efficient buildings	3. Heat transfer	9 activities
	4. Testing a model building	3 activities
	5. Energy efficiency at school	6 activities
3. Sourcing and protecting energy	6. Global warming	6 activities
	7. Energy generation	6 activities
	8. Wind energy	4 activities
	9. Solar energy	2 activities

3.3 Piloting of ENERGE Teaching and Learning Materials

Feedback from piloting of ENERGE activities was provided by two different teachers with their physics class groups in Luxembourg. Teacher 1 completed Activity 1.2 Calculating the cost of energy in the home. The activity was developed by a teacher of science and technologies of industry and sustainable development (STI2D Bac program) in France who was a member of the ENERGE teacher network. This activity was piloted with a co-educational class of 20 upper second level students (aged 16–20 years) studying a physics curriculum under the "General technical division" of general secondary education in Luxembourg. Teacher 2 completed Activity 1.5 My thermal comfort at home. This activity was developed through the collaborative efforts of the ENERGE Teacher Network and was piloted with a co-educational class of 16 upper second level students (aged 16–18 years) studying the Environmental sciences (SE) curriculum of the general technical division of secondary education in Luxembourg. Both activities are numeracy and communication-based exercises where students determine the wattage of a range of household appliances and their favourite devices and used the energy and power formula to convert between physical units to domestic energy units of energy (kWh) and applied a monetary value to the energy consumed.

Activities 1.2 and 1.5 shown below in Table 5 are taken from ENERGE Unit 1 and were selected by the teacher as relevant to existing topics on the physics curriculum in their region. The selected activities aimed to develop student energy literacy by student's personal use of energy in and examine their home environments to explore and debate issues surrounding energy use, energy conservation and energy efficiency in the home. Activity 1.2 Calculating the cost of energy in the home, aimed to address all five energy literacy characteristics, while Activity 1.5 My thermal comfort at home addressed characteristics C1, C3, C4, C5.

4 Teacher Feedback on ENERGE Activities

Feedback was collected from the two teachers that piloted ENERGE activities in their physics classroom. Teachers highlighted the suitability of the materials for their physics curriculum.

> The knowledge and skills outlined in the approach are relevant to the topics of mechanical and electrical energy on the physics curriculum. For example, the students would learn what is electrical and mechanical energy, how it can be calculated, how much energy is consumed by different devices and what is the cost of this energy (Teacher 1).

Teachers identified what skills each of the two activities, 1.2 and 1.5, focussed on. Decision making, critical thinking, numeracy, problem solving, and communication were rated the highest by both teachers (shown in Table 6).

Teacher 1 and Teacher 2 both expressed that the student learning outcomes mostly focussed on the cognitive domain particularly on knowledge of energy science and systems and managing energy resources. In their feedback, the teachers emphasised the opportunity to develop student's core skills and competences, such as numeracy, communication and decision making.

> The lesson worked well; students completed the exercise in small groups. As an exercise it also provides an effective overview of how much energy is needed for one household and the price of that energy which is important for decision making around energy and managing a household. (Teacher 1)

> The lesson was enjoyable and effective at getting students talking about the issues. These students were advanced in their level so while the calculations were easy for them the real merit for the activity comes from the opportunities for them to communicate and speak in English. (Teacher 2)

Table 6 Teacher's rating of skills developed through ENERGE activities

	Pilot 1 (Activity 1.2)	Pilot 2 (Activity 1.5)
	Rated on scale of 1 to 5, where 1 is to a little extent and 5 to a great extent	
Decision making	1	4
Problem solving	5	4
Innovation/creativity	1	2
Data analysing	3	1
Numeracy	5	4
Collaborating	3	1
Communicating	3	5
Research	1	1
Critical thinking	3	4
ICT/digital	3	1

Teacher 1 and Teacher 2 provided feedback on how the focus of the activities aligned with their relevant physics curriculum.

> I wanted students to get an overview of how much energy is needed for one household and the price of it, the materials provided were clear and effective in their learning aims. (Teacher 1)

> The topic of the activity was relevant. These students were advanced in their scientific education so while the calculations were easy for them the real merit for the activity comes from the opportunities for them to communicate and speak in English which they are practising and is an important part of their environmental science (SE) education. (Teacher 2)

5 Student Feedback on ENERGE Activities

Students provided feedback on their experiences of completing Activity 1.5 My thermal comfort at home (Pilot 2). Students expressed that they were more inclined to think about how much energy that they are using and planned to make changes to their energy consumption habits.

> As a vlogger, I actively create video content and acknowledge the energy costs but not just computers, it's also the data centre that stores and processes the digital content we create. I could disconnect electrical devices that are not in use from the network to save energy. (Student 1)

> I was surprised by the amount of money that it costs to run my devices, I never calculated it before. For the future I think I could take more public transport and not use my car so much. (Student 2)

6 Conclusions

At second level, the concept of energy is commonly taught as a cross-cutting concept in science and students build their knowledge about energy around four central ideas: energy transfer, transformations, dissipation, and conservation. This study presents the design and implementation of a pedagogical approach to develop student energy literacy at second level. Feedback from piloting with two teachers in the physics classroom indicate that the ENERGE activities had strong curricular alignment with the physics syllabus and successfully developed student energy literacy in multiple domains. These findings have implications for achieving the long-term objectives of ENERGE and highlight that successful implementation requires continued collaboration between key stakeholders including teachers, governing bodies, and national energy authorities.

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An Assessment Rubric for Future Teachers' Ability to Design Experiments

Ioannis Lefkos

Abstract Designing an experiment is a challenging task for most learners. In this work, we are proposing the use of a rubric for the assessment of future Teachers' ability to design experiments. The rubric comprises 6 dimensions and 3 levels of success of the learners' designs and is administered as a paper & pencil task. Learners are asked to answer various problems, by designing relevant experiments using Worksheets, that are specially designed to match the dimensions of the rubric, facilitating the data collection. Results from a pilot study revealed that using this assessment scheme we were able to detect the learners' difficulties in forming a hypothesis and in manipulating variables, and we were also able to identify possible reasons related to these difficulties. This rubric can easily be applied to a variety of educational conditions, functioning not only as a formative assessment tool for the teachers, but also as a scaffold for learners monitoring their own development.

Keywords Design of experiments · Manipulation of variables · Formulation of hypothesis

1 Introduction

Laboratory work and students' engagement in inquiry-based approaches are highly appreciated in science education as a means of promoting students learning [1, 2]. The importance of developing the inquiry skills of the students is not only limited in their science learning, but it is also considered to be providing them tools for dealing with problems of their everyday life [3] or their workplace [4]. On the other hand, teachers seem reluctant to adopt them [5] and the obstacle most commonly reported is the lack of time needed for these approaches to be implemented in school or the lack of instruments and devices to conduct the experiments [6]. In order to change these views, an important role can be played by providing proper training to future teachers at the university, with opportunities to experience and develop their skills

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in designing investigations [7], or designing and using appropriate evaluation tools targeting their learning goals [8].

Experimental work is a central component of inquiry-based approaches and the inquiry learning cycle [9]. However, the process itself of engaging students in experimentation is not unanimously defined, and a variety of ways of describing it have been proposed. Emden & Sumfleth [10] have reported on the variety of models, suggested by a number of researchers or institutes for inquiry processes in experimentation. Most of these models are arranged in a 3–5 stages process, where one of the stages is usually called “design” or “plan & design” and is the preparatory phase where one properly designs an experiment, before conducting it, in order to answer a research question. On the other hand, these models also present some differences. For example some models consider the hypothesis (or question) as a distinct phase, rather than part of the “design” or that conducting the experiment is sometimes considered to be part of the design phase [10].

In this work, we are focusing on the “design” phase of experimentation, as being a separate phase preceding the execution of the experiment, also considering the hypothesis as part of the design phase, following similar models (e.g. Schreiber [13] as mentioned in [10]).

Considering the design of experiment (DoE) as a distinct phase (even disconnected from the actual execution of the experiment), offers the advantage of easy and quick implementation of related activities and therefore leading to the enhancement of the relevant abilities of our students, overcoming the reported difficulties of time constrains or lack of infrastructure [6]. Furthermore, DoE activities can be applied independently of the laboratory environment (e.g. real, virtual laboratory) in which the experiments will (probably) be performed in a subsequent phase, or whether the methodological approach for practicing experimentation it is explicit or implicit [11].

In the following we will first define the basic elements for designing an experiment, also called “dimensions” [12, 13], and based on these dimensions we will propose a rubric for assessing future teachers ability to design experiments.

2 Designing Experiments

Designing an experiment in order to give an answer to a problem or a question, is probably the most challenging stage in experimentation [14] and various difficulties have been identified in learners of all ages, ranging from primary school to university students [15]. It is sometimes considered to be more important than even conducting the experiment itself [16]. It is perhaps the most demanding phase of the inquiry cycle [2], therefore one of the most important parts of inquiry [17]. The design process is a higher mental process that requires critical thinking skills, and is far from simply reading and following instructions, as may be the case in a traditional laboratory approach that is more focused on developing laboratory techniques and learning how instruments work [18]. This requirement for critical thinking and reflection when designing experiments is also indicated by some researchers [19], identifying it as an "ability"—rather than a skill, a view which we also adopt.

The DoE procedure required to solve a given problem includes several dimensions (Fig. 1) i.e. steps, like the expression of a hypothesis, the identification of the variables that influence the phenomenon, the strategy for managing the variables so that the results give valid conclusions, the selection of the required materials/instruments/ devices required, the design of an appropriate description of the process for taking/ recording the measurements and finally the definition of the criteria concerning the hypothesis evaluation and drawing a conclusion [2, 17]—not necessarily in this specific order.

Research on the ability to design experiments at the university level is mostly focused on Engineering or Science majors [19, 20]. Empirical studies report particular difficulties in some of the dimensions of DoE, e.g. in forming a hypothesis based on scientific criteria, or in properly handling the variables [17, 21, 22], or other topics such as understanding the problem or interpreting the data [15]. Some of the main reasons for these difficulties are considered to be the incomplete knowledge of the scientific content [15, 23], or the different kinds of variables that the participants are asked to manage (p (e.g., whether they are continuous or discontinuous, whether they are salient or not, etc.) [15, 24].

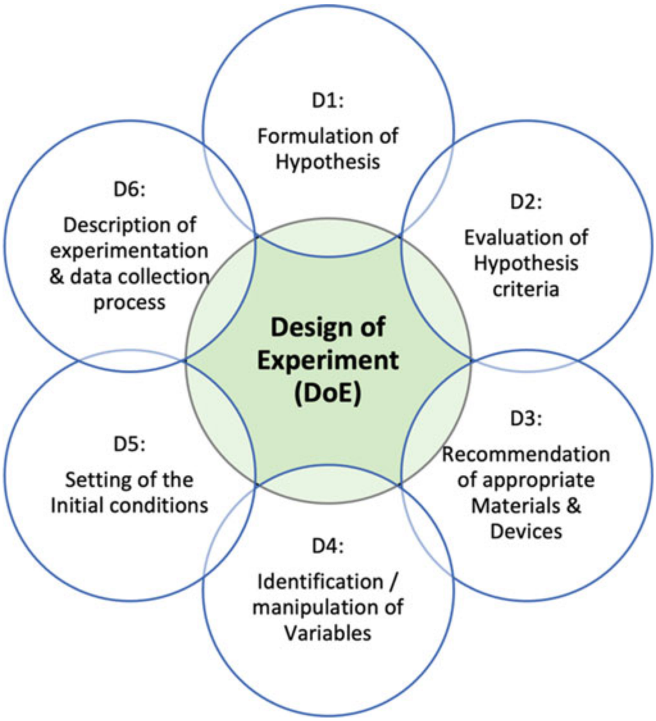

Fig. 1 The dimensions of Design of Experiment proposed in this work

In our view, assessing and developing this ability of DoE for future Primary School Teachers (PSTs) is also very important [25] in order to promote their engagement in similar tasks with their students, since it has been found that the ability to design experiments begins to develop already in elementary school students [26] and can also be promoted with appropriate educational interventions [11, 13].

In this work we are proposing an assessment scheme for the DoE based on a rubric, suitable for assessing the ability of future PSTs and we will also provide some evidence from a pilot study, using this scheme with a group of future teachers. The aim of this study was to check whether this scheme is capable of detecting difficulties in DoE of future PSTs. The results are discussed in relation to their possible implications for the education of future teachers.

3 An Assessment Scheme for the Design of Experiments

Various methodologies have been proposed for accessing the DoE, such as interviews [27] or questionnaires [2, 25, 26]. However, rubrics are a special category. The use of a rubric for the evaluation of the design of experiments might hold an advantage over other methods, as it can be used not only as a diagnostic tool, but also as a formative one, functioning as a scaffold in order to guide the participants in developing their abilities [19].

Some of the rubrics that have been proposed by other researchers were quite complex for our target group being future Primary School Teachers (PST). For example, the work of Komives and her team [18, 28] was targeted to students from a Polytechnic school, or similarly, the one proposed by Dasgupta et al. [15] was targeted to students from the Faculty of Biology. Hence, in the present research, we considered as more appropriate a rubric that has been proposed for the evaluation of the design of experiments by primary and secondary school students [13] since it was closer to the profile and abilities of our target group. A detailed presentation of the rubric can be found in the methodology section. The rubric is based on the dimensions of DoE presented earlier in this paper (Fig. 1).

An additional characteristic of the proposed assessment scheme is the fact that in order to collect the DoE data of the participants, a specially constructed Design of Experiment Worksheet (DoE-WS) is used, comprising a few simple open-ended questions. The answers provided in these questions can be easily juxtaposed to the dimensions of the DoE rubric. The choice of open-ended questions offers a balance between the degrees of freedom offered to the participants and on the other hand facilitates the researcher, providing the practicality of collecting results that will be easily comparable to each other [10]. In addition, it offers the advantage of an easy and quick implementation and data collection in the context of an educational process, without spending valuable teaching time and furthermore with no special equipment requirements [6]—both very important issues for its adoption by teachers. Moreover, such a DoE-WS offers the flexibility of solicitation in any educational setting, either in face to face or in distance education.

In our assessment scheme DoE comprises a set of sub-abilities (i.e., dimensions). Adopting elements of a rubric used elsewhere [13], in this work we propose using 6 dimensions and 3 levels of success, thus defining a 6 by 3 rubric for assessing future PSTs ability to design experiments. The dimensions assessed by this rubric are: (i) Hypothesis formulation, (ii) Criteria of hypothesis evaluation, (iii) Necessary materials & devices recommendation (iv) Dependent/independent variables identification & manipulation, (v) Initial conditions setting and (vi) Experimentation & data collection process description.

For the evaluation of the DoE, each one of the aforementioned dimensions is assigned 3 levels of success and awarded 1 to 3 points respectively. The total score of each learner can be calculated by summing the points from all dimensions (max $6 \times 3 = 18$). The specially constructed worksheet DoE-WS is used for prompting and recording learners' answers in each dimension. This worksheet works both as a scaffold for learners' designs and at the same time facilitates the data collection for the assessment of the DoE.

Moreover, using this scoring scheme, it is also possible to make comparisons between the level of success for each individual dimension of the DoE, by summing up all the participants' scores for every single dimension. This way we can compare different groups of learners or different DoE tasks.

As an example, the levels of success for the dimension of hypothesis formulation are displayed in Table 1. Since the original scheme [13] was proposed for high school students, these levels were adjusted to better fit the future PSTs levels of success, enhancing the rubric's granularity, using a content analysis approach on their answers.

In a pilot study 115 designs of experiments of future PSTs, were assessed at the beginning of the spring semester. Using this rubric, we were able to probe their difficulties in some dimensions, like the hypothesis formulation or the manipulation of variables, as also reported elsewhere [15].

Table 1 The levels of success for the hypothesis formulation according to the proposed rubric

Success level	Dimension: hypothesis formulation	Points
Level-1	Learner formulates a hypothesis based on alternative conceptions or incorrect assumptions	1
Level-2	Learner formulates a hypothesis based on scientifically accepted assumptions	2
Level-3	Learner formulates a hypothesis based on scientifically accepted assumptions, also using scientific terminology	3

4 Methodology of the Pilot Study

4.1 Research Questions

The research questions that we aim to answer with this research are the following:

RQ1. Is the evaluation rubric proposed in the present paper, capable of identifying the possible difficulties in the DoE of future teachers?

RQ2. Is the success of future teachers' DoE related to characteristics of the problems, based on which they are asked to design their experiments?

4.2 Sample and Conditions of the Research

The present research was conducted in the context of a Science Education course attended by 4th-year university students—future PSTs. During the course, students are familiarized with basic concepts of science, such as heat and temperature, electric circuits, states of matter, water solutions, etc. Moreover, theoretical issues are being discussed, like the learning theories and students' ideas in science, and also methodological approaches, such as inquiry-based learning, while they also practice designing and conducting investigations.

The data presented here were collected from four (4) diagnostic tests, each one dealing with a different problem to be solved by designing an experiment, using the Design of Experiment Worksheet. The tests were administered at the beginning of the courses, where the theoretical introduction to the course is made, with reference to learning theories. Therefore, responses were collected prior to any discussion about the teaching approaches like inquiry, the design of investigations etc., and also prior to discussions about the concepts and phenomena mentioned in the diagnostic tests. Thus we consider these tests to be portraying the students' initial views about the DoE.

The sample comprises students attending the course in 2020–2021, so in this sense it is not a representative, but a convenient sample. Of the answers collected, 115 are used in the following analysis (Problem A: 30 answers, Problem B: 30 answers, Problem C: 28 answers, Problem D: 27 answers), while those answers that were off-topic or left blank, were considered invalid. The answers were evaluated anonymously and without recording other characteristics of the participants, such as age, gender, language, origin, etc.

4.3 Content of Diagnostic Tests and Data Collection

Data were collected using the Design of Experiment Worksheets, where students were asked to design an experiment in order find the answer to a given problem (4 different problems were addressed in this study—see Table 2).

The problems students were facing in the Worksheets were chosen appropriately so that they were related to their everyday experience, they can be conducted using easy-to-find/everyday-use materials and could be approached qualitatively or semi-quantitatively. They were practically thought experiments with no need for very specific measurements and calculations.

For example the wording of a problem, related to thermal radiation, was the following: "When you try to keep your water cold for as long as possible during a summer day, is it better to use a black or a white cup? Or is it the same? Explain in a few words, why do you think this is happening?"

Following the prompts of the DoE-WS, students initially had to formulate a hypothesis, mention the materials and devices needed for doing the experiment, identify and manipulate the variables affecting the phenomena under study, decide about the initial conditions to be set, describe the procedure of experimentation and data collection and finally propose the criteria for the evaluation of their hypothesis. In other words they were prompted to answer the questions, taking into account the 6 dimensions of the DoE, proposed in this work.

On the other hand, being informed by the literature related to the difficulties that learners present in DoE [15, 17, 21–24], the problems were also chosen to be different in 2 distinct characteristics:

- Whether the phenomena under study were intuitive or counterintuitive. For example, the problem related to the absorption of thermal radiation is intuitive, but the problem related to the emission of thermal radiation is counter intuitive and misconceptions have been reported even among engineering students [29].
- Whether the phenomena under study involve the manipulation of a small number of variables or a large one. For example, solubility problems involve only a couple

Table 2 The problems given to the students to prompt their DoE, their content and their characteristics

Problem	Phenomena under study	Intuitive/counterintuitive	Complexity/number of variables
A	Solubility versus temperature	Intuitive	Small number
B	Solubility versus temperature	Counterintuitive	Small number
C	Thermal radiation versus color	Intuitive	Large number
D	Thermal radiation versus color	Counterintuitive	Large number

of variables like the quantity and the temperature of the water and the quantity of solute. On the other hand, radiation problems are more complex and involve handling more variables like the quantity and temperature of water in each cup, the temperature of the environment, the color of each cup (and other properties to be controlled) and the time.

This way we can put our proposed framework to test, to investigate whether it can successfully detect similar difficulties of our sample group of students.

5 Results

After collecting the data from the participants, following the scoring scheme presented earlier, the scores of each participant and each task were calculated. In order to be able to make comparisons between the different tasks, the overall score for each dimension was also calculated by adding up the score of all participants in each dimension. Since the answers collected for each task were not exactly the same, the overall score was also converted to a percentage, for facilitating the comparisons. The results from the scoring (%) per individual dimension of DoE for each of the problems presented to or sample of future PSTs are presented in Fig. 2.

In general, it can be seen that apart from a few exceptions, the performance of the participants in most of the Dimensions was quite high. However, at the same time, some similarities and some disparities can be observed, between the various design problems. For example, there is a similarity in the high success rates of D1 in tasks A & C (success 86% and 76% respectively) with a simultaneous differentiation of the same dimension in tasks B & D (38% and 36% respectively). In addition, there is a similarity in the high success rates of D4 between tasks A & B (78% and 81% respectively), with a simultaneous differentiation of the same dimension in tasks C & D (62% and 53% respectively).

In other words, there is a first indication of differences existing in Dimensions D1 and D4, probably related to the various characteristics of the design tasks. For a closer view on this issue, a statistical analysis will follow below (using SPSS v27).

5.1 Statistical Analysis

In order to investigate the possible correlations of the independent variables (Dimensions D1-D6 of experimentation) with the dependent variables (the problems, their complexity, and whether they were intuitive or not), the following methodology was followed.

At first, the distribution of the data was tested. As presented in Table 3, in all cases ($p = 0.000$) the null hypothesis is confirmed (H0 = data distribution differs from normal), meaning that the data do not follow the normal distribution.

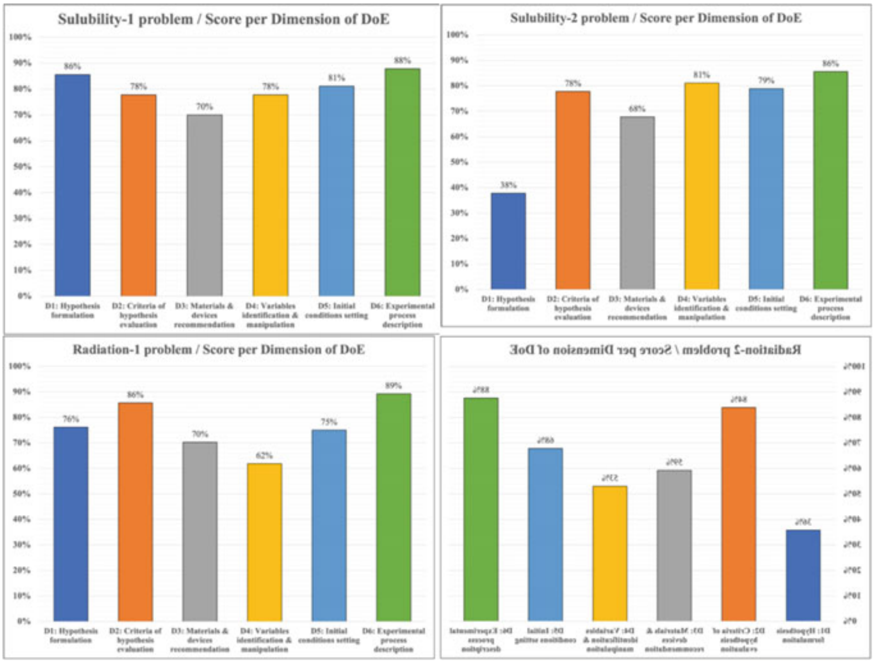

Fig. 2 The scores (%) per dimension of the Design of Experiment for the four (4) different design problems presented to the future teachers taking part in this study

Table 3 Tests of normality

	Kolmogorov-Smirnov[a]			Shapiro–Wilk		
	Statistic	Df	Sig	Statistic	df	Sig
D1	0.351	115	0.000	0.695	115	0.000
D2	0.316	115	0.000	0.730	115	0.000
D3	0.279	115	0.000	0.797	115	0.000
D4	0.252	115	0.000	0.806	115	0.000
D5	0.281	115	0.000	0.779	115	0.000
D6	0.407	115	0.000	0.645	115	,000

[a]Lilliefors Significance Correction.

The next step was to investigate the differences presented in the scoring of the six dimensions of DoE, in relation to the different design tasks. Since the data are not normally distributed, non-parametric tests were used for this investigation (Table 4). The null hypothesis under test was: H0 = distribution of Dimension-X is the same for all design tasks.

As displayed in Table 4, dimensions D1 & D4 are differentiated across tasks, meaning that the content and characteristics of the design tasks have an effect on the

Table 4 All dimensions are not the same for all tasks: dimensions D1 & D4 are differentiated across tasks

	Null hypothesis	Test	Sig.[a,b]	Decision
D1	The distribution of D1 is the same across categories of Group	Independent-Samples Kruskal–Wallis Test	0.000	Reject the null hypothesis
D2	The distribution of D2 is the same across categories of Group	Independent-Samples Kruskal–Wallis Test	0.278	Retain the null hypothesis
D3	The distribution of D3 is the same across categories of Group	Independent-Samples Kruskal–Wallis Test	0.223	Retain the null hypothesis
D4	The distribution of D4 is the same across categories of Group	Independent-Samples Kruskal–Wallis Test	0.000	Reject the null hypothesis
D5	The distribution of D5 is the same across categories of Group	Independent-Samples Kruskal–Wallis Test	0.274	Retain the null hypothesis
D6	The distribution of D6 is the same across categories of Group	Independent-Samples Kruskal–Wallis Test	0.909	Retain the null hypothesis

[a]The significance level is 0.050
[b]Asymptotic significance is displayed.

scoring of specific dimensions, namely on the dimension concerning the formulation of hypothesis and the dimension concerning the manipulation of variables.

Consequently, these results answer our RQ1, since they provide evidence that the evaluation scheme proposed in this paper is capable of identifying the possible difficulties in the DoE of future PSTs.

Finally, the correlations of the various dimensions of DoE to the contents and characteristics of the problems were investigated using the Pearson test (Table 5). Indeed, a positive correlation was found between the D1 dimension and the intuitive/counterintuitive content of the tasks ($r(114) = 0.733$, $p < 0.001$). A negative correlation was also found between the D4 dimension and the number of variables ($r(114) = -0.464$, $p = < 0.001$).

In other words, when a design task is counterintuitive, this may result in lower scores in the D1, related to the forming of hypothesis. Additionally, when a design task is complex and demands the manipulation of many variables, this may result in lower scores in the D4 dimension, which is related to variables identification and manipulation.

These correlations are providing answer to our RQ2, as it seems that the success of future PST DoE is related to characteristics of the design problems.

Table 5 Pearson correlation test reveals the positive correlations between **a** D1 and the intuitive/counterintuitive task, **b** D4 and the number of variables involved in the design task

		D1	D2	D3	D4	D5	D6	Number of variables	Intuitive/ Counter
Number of variables	Pearson correlation	−0.088	0.179	−0.091	−0.464**	−0.174	0.053	1	0.009
	Sig. (2-tailed)	0.351	0.055	0.334	0.000	0.062	0.577		0.923
	N	115	115	115	115	115	115	115	115
Intuitive / Counter	Pearson Correlation	0.733**	0.023	0.144	0.048	0.092	0.057	0.009	1
	Sig. (2-tailed)	0.000	0.807	0.126	0.608	0.327	0.549	0.923	
	N	115	115	115	115	115	115	115	115

**. Correlation is significant at the 0.01 level (2-tailed)

6 Conclusions

Designing an experiment is an important stage in experimentation and future PST should be trained to acquire this ability. In this work, we have proposed a rubric for the assessment of the ability to design experiments in 6 dimensions, to be applied using a specially constructed worksheet as a paper & pencil task. Using this scheme, we were able to identify difficulties in some dimensions of future PSTs design of experiment and also point to the possible reasons for these difficulties.

Specifically, our assessment scheme revealed that when a design task is counterintuitive, future PSTs have difficulties in properly formulating a hypothesis. Additional difficulties were revealed, related to the complexity of the design problems. Hence, when a problem calls for the manipulation of a larger number of variables, it may result in a less successful design of experiment.

These findings can provide insights for the training of future PSTs, since educators might prefer to introduce the design of experiment starting from easier tasks and gradually proceed to more difficult ones. As shown in this pilot study, learners dealing with intuitive and less complex design tasks might result in a more successful design of experiments.

The abovementioned difficulties that learners present in DoE, are in line with previous research findings [15, 17, 21–24], but in this work we have presented an evaluation scheme, that on one hand is able to detect common difficulties in DoE, and on the other hand it can be easily administered in a variety of educational settings.

This kind of task and assessment scheme can be used for monitoring the development of the learners' ability to design experiments, but can also be used as a scaffold for the learners to self-regulate their learning process [19]. Moreover, it can easily be implemented even in large audiences, in f2f or distance education, since no laboratory equipment is used, bearing none of the obstacles commonly reported by the teachers [6] for implementing inquiry practices.

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The Influence of Digital and Paper-Based Homework-Solving Methods on Students' Academic Performance and Attitude Towards Physics

Dorottya Schnider and Mihály Hömöstrei

Abstract Teachers of physics continually try to keep up with the development of technology and the opportunities such developments present to make their classes as interesting and effective as possible. But should we always discard well-proven methods in favour of digitalised solutions? Our research investigates the long-term effectiveness of digital and handwritten homework assignments submitted by seventh grade pupils. The study discusses the effect of digitalized education on students' academic performance and cognitive development, investigates the role of handwriting in education—focused on homework solving—and compares it with the opportunities given by using digital methods, and supports physics teachers in choosing appropriate teaching methods based on the results of the research, which was carried out in Budapest among 7th graders—test and control group. The results indicate a significant decline in students' digitally acquired long-term knowledge.

Keywords Digital · Handwriting · Homework

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1 Introduction

1.1 Generational Differences in Education

For the twenty-first century teacher, being able to address as many pupils in the classroom as possible is a significant methodological challenge. The rapid changes in technology contribute not only to the changes in the way of life, but also to the development of new approaches in education [1].

According to generational theories, the encounter with the Internet defines different generational classes: from matures to Generation Z (our students) [2, 3].

1.2 Handwriting, the Traditional Way of Learning

There is a strong neurobiological link between handwriting and cognition. The cerebellum and the nerve centre responsible for the given activity cooperate in the course of performing several cognitive tasks. The neurological connection between the prefrontal lobe and the area of the brain responsible for motor operations are responsible for the development of both fine motor and cognitive skills. The development and use of fine motor skills both stimulate the prefrontal lobe. The same part of the brain is also responsible for the executive functions of the brain which, in turn, control our cognitive processes and our behaviour [4].

As brain researcher József Hámori [5] notes, the Broca area[1] of the brain is significantly activated during handwriting, but not during typing. Because this is also the area of the brain that is activated during communication, it seems obvious that handwriting and communication are related activities.

The higher level of brain activity observed during handwriting results in the development of cognitive abilities such as remembering, thinking, imagination, and so forth. All of this contributes to an efficient learning process and, hence, good academic performance. The high degree of brain activity may be one of the reasons why people tend to remember information better if they write it down, rather than type it out. Another important aspect is the fact that you need to devote time to whatever you wish to learn or master. And handwriting is much more time-consuming than typing. When you write something down, you also think about what you are writing and you make corrections on the way—in other words, you use your brain [5].

Mueller and Oppenheimer [6] observed the note-taking habits of university students. They found that if you take handwritten notes, you will probably abbreviate, condense and rephrase what you hear, using your own words, which allows you to remember the topic better, and give more precise answers even to complex, abstract questions regarding the topic.

[1] The motor centre of speech.

On the other hand, because handwriting is a basic learning skill, students with writing difficulties are at a disadvantage regarding their scholastic performance. In such cases, the use of digital tools and contexts may assist the process of studying [7].

1.3 Using Digital Tools in Teaching and in the Physics Class

Why and to what degree is it necessary to digitalise teaching, or to use digital tools in the physics classroom? We must allow digital technologies to enter the realm of education to a certain degree because we need to adapt to the needs and skills of the students formulated in the digital space.

Our living environment has changed. Our presence in the online space has an effect on our offline lives. Most pupils arrive from the online space to the offline reality—for instance, the physics class. Therefore, this offline reality needs to adapt to the pupils. Members of Generation Z have grown up in a world which offered them powerful and swift impulses. Therefore, they demand diversity in school, too. The use of colourful techniques and varied forms of working is also suggested because pupils tend to no longer be able to singularly focus their attention. Rapidly changing visual impulses and a continuous influx of new information have shortened the concentration span. Students find the digital environment natural, since that is where they have been socialised. Often, teaching needs to adapt to this reality [8].

Digital teaching can allow pupils to actively participate in the lesson—using their own mobile equipment, even–, to get involved in work processes such as a measurement and the analysis of data, the observation of an animation or simulation, and thereby build their set of knowledge through individual discovery and personal experience. All of this requires the development of a suitable digital educational methodology.

The nervous system is built through experience, therefore parents and teachers should all ensure that the, yet undeveloped nervous system of children receives stimuli that assist development. Smartphone games cannot replace playing with Lego, and chatting is no substitute for talking in person. For the undeveloped nervous system, it is important that as many senses are used actively as possible. That allows the child to experience, discover and learn about the world around them, about human emotions, as well as the workings of human relationships. Most members of Generation Z do not experience the process and joy of discovery and learning [9]. While the use of screen presents various forms of danger, it is part of our daily life, and there is a significant demand to use such digital tools in the classroom. By using them in a methodologically appropriate manner, digital technology could allow individual discovery to take place within the lesson.

2 Research Method and Research Design

Empirical research to address the problems mentioned above was organised in the school year 2019/2020. The basis of the research was a pilot project that aimed to investigate the role of digital and traditional teaching methods in education. Because the authors—both of them are physics teachers—had no opportunity to exclusively use either one of these methods in their teaching, the study focuses on completing the homework digitally and in handwriting. The authors observed the effects that paper-based and digitally solved home assignments have on cognitive processes, and investigate which methods allow for the acquisition of long-lasting, solid knowledge. The aim of the research was to investigate the influence of different methods on students' attitude towards learning physics, too. The investigation was conducted with test and control groups. Pre-test was used to observe any significant differences in the experimental and control group of students' knowledge. Post-and follow-up tests were used to assess students and make statistics and identify any effects of the applied homework-solving methods on students' academic performance—long-term information processes—and on their attitude towards the subject.

2.1 Sample

The research was carried out in Fazekas Mihály Primary and Secondary School. The investigation was organized within one class—7th graders—all were 12–13 years old. The research activity was considered to be a useful learning opportunity for the students, the teachers dealt with the topic of kinematics in 7th grade as the curriculum states. Primary school students were observed, who had two 45-min-long physics lessons per week in the school year of 2019/2020. The class was randomly divided into 2 groups: $n_{test} = 14$, $n_{control} = 11$. The experimental group completed homework digitally, the control group solved the same homework in handwriting.

2.2 Instruments

Lesson plans. The experimental and control group attended the same traditionally organised lessons, and followed the same syllabus and same lesson plans. The research focused on solving homework assignments with different methods, thus the lessons were prepared according to the teachers' own philosophy:

1st lesson: Reference systems.
2nd lesson: Straight line motion with constant velocity.
3rd lesson: Practice.
4th lesson: Changing motion—in general.
5th lesson: Straight line motion with constant acceleration.

6th lesson: Measurements and student experimentation.
7th lesson: Free fall.
8th lesson: Vertical throw.
9th lesson: Practice.

During the teaching process, the teacher used varied methods and colourful techniques, e.g.: pair work, group work, traditional and digital theoretical and counting tasks, storytelling or picture description, etc. in the lessons. In the classroom, students experienced both traditional techniques and ones afforded by digital tools, e.g., online games, videos or simulations, depending on how much the subject in question allows for these. This way, the students had the opportunity to meet the two—digital and traditional—techniques and formulate an opinion about them.

Homework assignments. During the investigation, the students had to complete home assignments for each class. The test group had to complete digital homework in an online classroom created by the teacher—using Google Classroom—and the control group solved the same homework in the traditional, paper-based way. The exercises were completely identical, except for their format—there were no further changes or transformation.

The digital homework was formulated as open-ended questions with short answers, as well as multiple choice questions with a single correct solution. When choosing the tasks, the teacher had to make certain that they were suitable for the age group, and that they could be solved digitally. For the purpose of the research, it was important that pupils working digitally should not use paper-based techniques for solving the tasks; that they should not also work in writing. When devising the digital task, the authors were aiming to minimise all traditional traits, as well as to give the students tasks that could be solved digitally in a meaningful way. A popular, non-traditional method of digital testing is the multiple-choice format. Most online test editor programs support multiple choice questions. These can be automatically graded and pupils receive instant feedback on their performance. This is not possible for open-ended questions, as the computer will mark the response wrong even if it is only off by a single space. In light of all of this, the teachers chose questions for which pupils could pick the right answer from among a number of options. For tasks where calculations were necessary, they presented various solutions. Different sequences were entered, giving the students ready-made solutions, out of which they had to pick the correct one (Fig. 1).

After students have submitted their answer, they received automatic feedback, confirming instantly whether their solution was correct. Pupils working on paper received no such support. They had to remember what they had learnt in class, recreate the correct way of solving the question, and write it down in their exercise book. Also, they didn't receive feedback on their work until the next class when the homework was checked.

Tests. During the investigation, students learnt the theory and practice the subject. During the practice stage, the students had the opportunity to solve traditional problem-solving tasks, counting tasks with the support of the teacher. At the beginning of the research, the students took a preliminary test, which contained some basic theoretical questions. The Hungarian students start learning physics in 7th

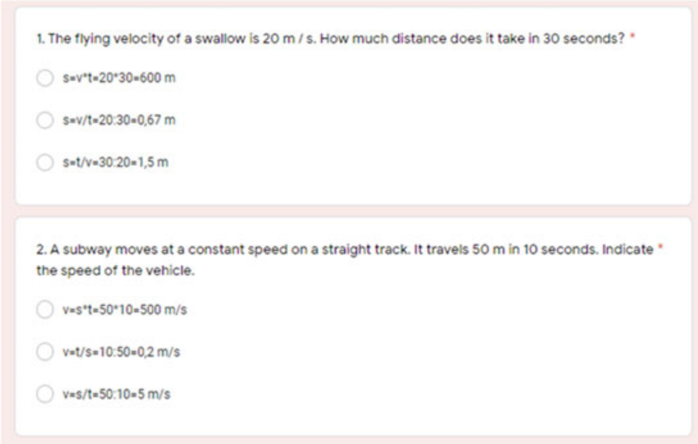

Fig. 1 Online homework in Google Classroom. Is it more efficient than handwritten homework?

grade. Before the topic of kinematics, they got acquainted with physics in general, and they learn about some measurement possibilities, thus they also had some basic knowledge in physics. At the end of the unit, the students took an end-of-unit test (post-test) which contained both theoretical questions and counting tasks. In order to investigate the effect of different methods on the development of long-lasting knowledge, the student took a follow-up test 2 months later. It was not announced in advance, but contained completely the same exercises as the post-test. The authors—students' teachers—knew the identities, because the students had to write their name on the answer sheets.

Research questions (RQs). The teaching experience of the authors confirmed that it is worth investigating the research problem based on the following research questions:

(1) Is digital homework more effective than traditional handwriting-based homework? Is there any significant change in students' academic performance influenced by the applied homework-solving methods (follow-up test results compared to pre-test results)? If yes, is there a correlation between this effect and students' gender and their previous knowledge?
(2) Is there any significant change in students' attitude towards specific elements of a physics lesson?
(3) What is students' opinion about the role of traditional and digital methods in academic development?

Research model. The research model can be seen in Fig. 2.

To investigate whether digital or traditional way of completing physics homework contribute better to the development of solid, long-term knowledge, and to find out students' opinion about the motivating effect of the used methods, the authors

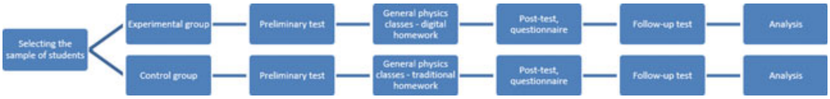

Fig. 2 The research model

selected the sample of students for their research. They organised the students into two groups—test and control group.

At the beginning of the research, the students took a pre-test in order to check whether there are significant differences between students' knowledge from the two groups. Then, pupils got the same instruction about kinematics. The students had to prepare homework for each class, the descriptions of the tasks were the same, but students in the difference groups had to complete them in different ways—the experimental group solved digital homework, the control group solved paper-based homework. At the end of the unit, students took a post-test and filled out a questionnaire. The students had to indicate their opinion about the applied methods and specific elements of a physics class on a 4-point Likert scale: I completely agree—I agree—I disagree—I completely disagree. In order to investigate the long-term effects of the two methods, students took a follow-up test 2 months later in the first phase of the research. After the testing and assessment, the authors statistically analysed the results.

3 Results and Discussion

3.1 Statistical Methods

The statistical analysis of data was accomplished by JASP statistics software [10]. The authors applied Shapiro–Wilk test [11] to investigate whether the data fits the normal distribution. In order to analyse the preliminary test results, the authors compared students' achievement with the application of Independent T-test [12]. If the data fit the normal distribution, the authors can apply F-test [13] to check whether the population variances are equal or not. Independent T-test is used when the data fits the normal distribution and the variances are equal in the two populations, Welch-probe is applied if they are not equal.

To see if there were significant difference between the effect of the applied homework-solving methods on students' long-term information processes, the authors used Student-t test: Paired Samples t-test [14] for normal distribution. If the data do not fit the normal distribution, they apply Wilcoxon signed-rank test [14] for the analysis—the data pair comes from the two test results (post-test and follow-up test) taken by the same student.

The authors used Student-t test (Paired Samples T-Test) [14] mentioned above to analyse and interpret students' answers given on the questionnaire.

Table 1 The result of the independent samples T-test—preliminary test

Independent samples T-test			
	t	df	P
Preliminary test	0.512	23	0.613

3.2 Results of the Investigation

The results of the preliminary test. For the comparison of data Independent Samples T-Test was applied. The results of the Shapiro–Wilk test were the following. Test group: $p = 0.111$; control group: $p = 0.167$. The test of equality of variances: $p = 0.936$. The p-value of the T-test indicates that there is no significant difference between students' knowledge. (Table 1)

The results of the Paired Samples T-Test. The test results of the groups fit the normal distribution (p-value of Shapiro–Wilk test in the test group: 0.999; in the control group: 0.232), the p-value of the applied Paired Samples T-test does not indicate significant different between the two measurements—summarized results: post-test: 78.45% and follow-up test: 76.45%—, but there is a slight reduce in the academic performance of those students who solved digital homework—summarized results: post-test: 75.29% and follow-up test: 68.86%. Within 94.6% confidence interval, one can state that there is a significant decline—loss of knowledge over time—in the test group (Table 2).

The results of the questionnaire—The opinion of students. The authors examined the students' attitude towards specific components of a physics lesson based on their answers indicated on a Likert-scale. They compared it to a basic attitude, 'I find physics interesting'. According to the applied Paired Samples T-Test, the attitude towards demonstration experiments was significantly more positive compared to the basic attitude (reference value) of students working digitally, while the attitude towards problem-solving tasks was significantly more negative for students working traditionally (Figs. 3 and 4).

Furthermore, the students had the opportunity to give their opinion about the applied methods. They underlined those statements of the questionnaire that they found true for themselves. Figure 5 shows students' opinion. Note: we marked in green those statements, that were chosen by more than half of the group, in red the

Table 2 The results of the Paired Sample T-Test. The comparison of students' post-test and follow-up test results

Paired samples T-Test in the test group					
Measure 1	Measure 2	t	df	p	
Post-test	–	Follow-up	2.114	13	0.054
Paired samples T-Test results in the control group					
Measure 1	Measure 2	t	df	p	
Post-test	–	Follow-up	0.784	10	0.451

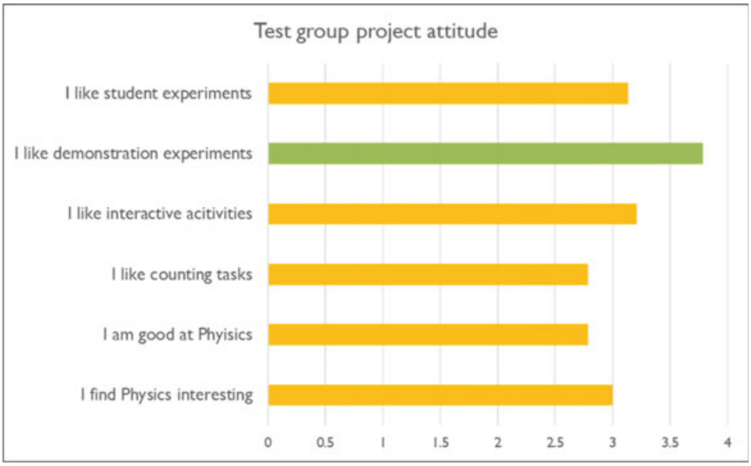

Fig. 3 Test group attitude towards learning physics

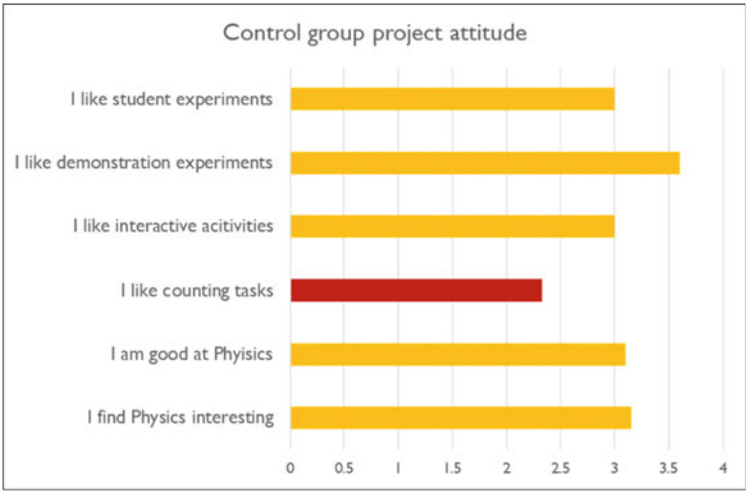

Fig. 4 Control group attitude towards learning physics

statements received few markings, and in yellow those that were marked by about half of the students.

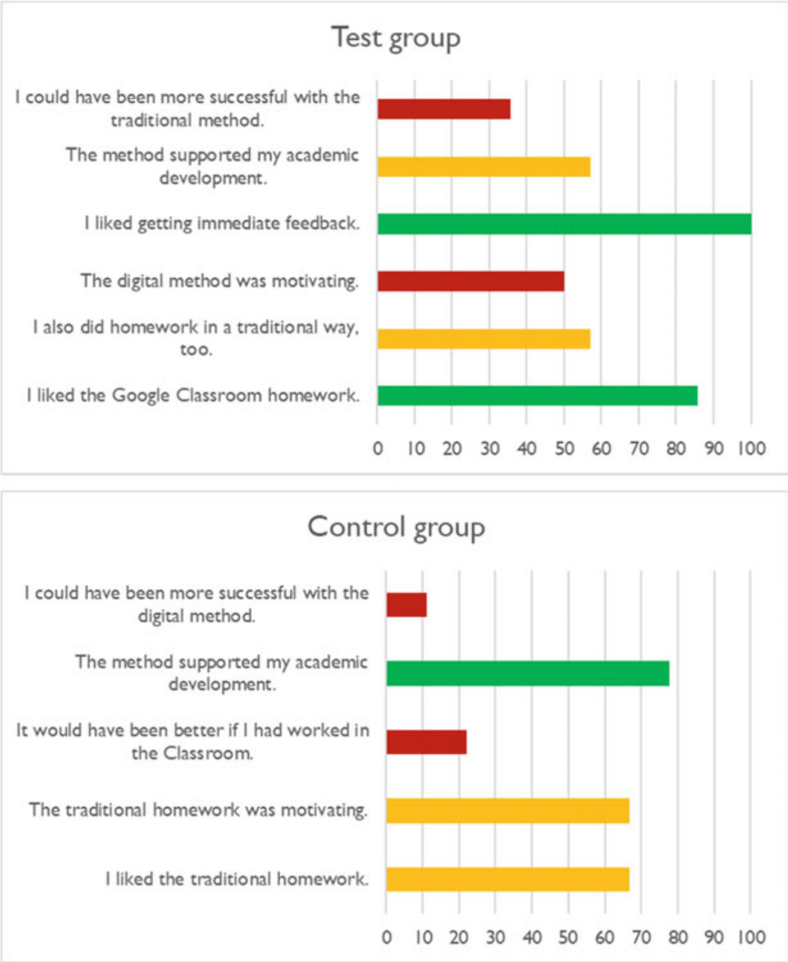

Fig. 5 Students' opinion on the applied methods

4 Conclusion

Our study has observed the efficiency of digital and paper-based methods in doing home assignments. Online tests are practical for working at home because pupils can receive instant feedback, while teachers can see their students' progress. However, our research showed no further advantage of this method. Pupils seem to have a similar attitude to traditional and digital methods, neither of them being particularly motivational. On the other hand, the majority of 13-year-old students believe paper-based work may be more effective than digital. While they obviously have a need for using digital tools in the classroom, they are also convinced that traditional methods might yield the best results. This effectiveness is also supported by the findings of the research, which showed that the long-term recollection of digitally acquired knowledge was significantly poorer than that of knowledge learnt through traditional paper-based methods. Our pupils could achieve a more thorough, deeper state of learning in a traditional environment, using traditional methods of learning. In this case, effective, quality learning still equates with the traditional. The results of the research confirm that you cannot simply transfer the traditional into the digital—as it is often done in practice—without negative side effects. Even though the authors made efforts to use a suitable question format and thereby reduce the traditionality of the task, they deem further research would be necessary to see what operators should be used in physics class, replacing 'traditional' methods.

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The Many Roles of Metaphors in Learning and Doing Physics

Magdalena Kersting and Rubén Sampieri-Cábal

Abstract In recent years, the physics education community has embraced embodied cognition perspectives to further explore the role of metaphors in the teaching and learning of physics. While researchers seem to agree on the crucial cognitive value of metaphors that can aid scientific inquiry, their instructional potential in physics education is not yet fully realized. In this paper, we first review the many roles of metaphors in learning and doing physics. Synthesizing insights from physics education research and the history and philosophy of science, we then suggest how the explicit use of metaphors can improve instructional practices in physics education.

Keywords Metaphor · Embodied cognition · Physics education

1 Introduction

Metaphors play a crucial role in science by providing aids to reasoning and imagination [1, 2]. Metaphors can also provide the basis of scientific knowledge that is too abstract to be understood through our senses alone [3]. Although the extent to which metaphors constitute an essential part of scientific knowledge is still a debated topic among scholars, there is no doubt that metaphors have excellent potential to improve instructional practices in physics e.g., [4–7]. However, there remains a gap between research and practice. While physics education researchers have drawn on embodied cognition perspectives to argue for the importance of conceptual metaphors [8, 9], few instructional practices make explicit use of such metaphors. In this paper, we address this gap and suggest ways of bridging it. First, we review the many roles of metaphors in learning and doing physics with a view toward physics education

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research (PER) and the history and philosophy of science (HPS). Second, we synthesize our findings to suggest how physics teachers can take advantage of the different roles of metaphors. Two research questions guide our inquiries:

1) Which role do metaphors play in learning and doing physics?
2) How can metaphors be put to good use in physics education?

2 The Role of Metaphors in Learning and Doing Physics: Insights from Physics Education Research

To understand the role of metaphors in learning and doing physics, physics education researchers have drawn on embodied cognition perspectives and conceptual metaphor theory [7, 9–12]. According to these perspectives, our understanding of physics concepts is grounded in our bodies: we extend embodied experiences to more abstract domains through *conceptual metaphors* [13]. Here, the role of metaphors in learning physics is **constitutive**: metaphors are cognitive mechanisms that evoke lived experiences as an experiential basis for the construction of abstract concepts. Repeated sensorimotor interactions with the world lead to the creation of image schemas which constitute phenomenological building blocks of cognition [14]. Such image schemas go hand in hand with characteristic inference patterns, and conceptual metaphors allow transferring these patterns to abstract domains. In the context of science education, Niebert et al. [12] interpreted conceptual metaphors as the imaginative principles that allow learners to imagine one thing in terms of another. Thus, conceptual metaphors are both a key mechanism for learning and closely tied to imaginative practices of reasoning in physics [15].

The rubber sheet model of spacetime represents one example of a popular conceptual metaphor in general relativity education [7, 16]. By comparing a two-dimensional malleable fabric (e.g., a piece of rubber, a trampoline, a pillow) to four-dimensional spacetime, the metaphor maps an experience-based source area to the abstract target area of spacetime. The goal of this mapping is to characterize gravity as a geometric feature of spacetime [16]. The rubber sheet metaphor, thus, enables a new way of revealing aspects of gravity by constructing similarities between embodied experiences of malleable fabrics and mathematical descriptions of spacetime [17].

A second type of metaphor extends the cognitive role of conceptual metaphors by focusing on full body engagement: *enactive metaphors* build on the idea that metaphorical meanings can emerge from human actions [10, 18]. More specifically, enactive metaphors are metaphors that students **enact**, i.e., that students bring into existence by putting the metaphor into action [18]. For example, Lindgren et al. [19] chose enactive metaphors as their instructional approach to teach the law of gravity in astronomy education. Students assumed the role of an asteroid and navigated through a mixed reality environment that depicted the solar system. Through the enactive metaphor "I am an asteroid", students explored how their bodies' motions corresponded to the motion of the asteroid in the solar system. Thus, the enactive metaphor was embedded in the mixed reality learning environment and brought to live by the students. This enactive feature of metaphors highlights how metaphors afford material mediation in processes of learning physics.

In summary, PER shows us that there are at least two distinct roles, the conceptual and enactive, that metaphors play in learning and doing physics. While conceptual metaphors transfer embodied experiences to more abstract cognitive structures, enactive metaphors demonstrate the relevance of action-based learning in physics. Thus, enactive metaphors are more than figures of speech or figures of thought—they are figures of action [20]. Both roles take their point of departure in embodied cognition perspectives, thereby adding deeper insights to our previous understanding of how metaphors and analogies help learners build bridges between source and target domains when they reason about physics phenomena [5, 6]. We now turn to HPS perspectives to see if we can identify further roles in the history of physics.

3 The Role of Metaphors in Learning and Doing Physics: Insights from the History & Philosophy of Science

To better understand the role of metaphors in learning and doing physics, we now turn to the history and philosophy of science. Many philosophers of science, including Hesse [21], Boyd [22] and Kuhn [23], have followed Max Black's [24] interactionist theory of metaphors. According to this view, metaphors are mechanisms through which two subject areas interact so that one subject can be understood in terms of the other. This interaction between ideas and concepts is not merely linguistic, i.e., a mere feature of a particular language game. Instead, metaphors can be cognitive projection tools that transfer properties from known to unknown phenomena. Thus, HPS scholars suggest that metaphors play a crucial role in scientific knowledge construction: metaphors serve as aids to reasoning, and specifically, **aids to the imagination** [1]. By suggesting directions of inquiry and improving our sets of representations, metaphors guide scientific thought [2]. Crucially, as imaginative mechanisms, metaphors create new meaning and guide physicists in their inquiry towards promising new insights, conceptualizations, and relationships.

Many historical accounts affirm this interactionist and imaginative view on metaphors as a tool to create new insights. The history of physics presents excellent case studies of scientists who employed metaphorical thinking to form radically new hypotheses and make novel discoveries, including Newton, Faraday, Maxwell, Einstein, and Feynman. In all these cases, we see that metaphors stimulated the scientific imagination.

1. Newton tried to understand the nature of light by comparing light to tennis balls that described curved lines after being hit by tennis rackets. This metaphor would lead Newton to develop his corpuscular theory of light [25]:

   "*Then I began to suspect whether the rays, after their trajection through the prism, did not move in curved lines, and according to their more or less curvity tend to divers parts of the wall. And it increased my suspicion, when I remembered* *that I had often seen a tennis ball struck with an oblique racket describe such a curved line* (…)" [25 p 97]

2. Faraday expressed his early intuitive conception of lines of forces in metaphorical ways. He conceived of these lines as vehicles that were moving, shaking and undulating when transmitting magnetic and electric forces [26]. Reflecting on his way of reasoning, Faraday stated:

   "*It is not to be supposed for a moment that speculations of this kind are useless, or necessarily hurtful, in natural philosophy. They should ever be held as doubtful, and liable to error and change; but they are wonderful aids in the hands of the experimentalist and mathematician. For not only are they useful in rendering the vague idea more clear for the time, giving it something like a definite shape, that it may be submitted to experiment and calculation; but they lead on, by deduction and correction, to the discovery of new phaenomena, and so cause an increase and advance of real physical truth, which, unlike the hypothesis that led to it, becomes fundamental knowledge, not subject to change.*" [27]

3. Maxwell expressed great confidence in physical analogies that he used as guiding aids to explore unknown features of natural phenomena. He postulated the aether as the medium of electromagnetic force transmission and used mechanical analogies to explore conceptual possibilities of the aether (e.g., "fluid", "elastic", "electrical", "medium") [26]:

   "*We must therefore consider the aether within dense bodies as somewhat loosely connected with the dense bodies, and we have next to inquire whether, when these dense bodies are in motion through the great ocean of aether, they carry along with them the aether they contain, or whether the aether passes through them as the water of the sea passes through the meshes of a net when it is towed along by a boat.*" [28 p 768]

4. In fact, Maxwell not only explicitly used, but encouraged the use of metaphors:

   "*The figure of speech or of thought by which we transfer the language and ideas of a familiar science to one with which we are less acquainted may be called Scientific Metaphor. Thus, the words Velocity, Momentum, Force, &c. have acquired certain precise meanings in Elementary Dynamics. […] These generalized forms of elementary ideas may be called metaphorical terms in the sense in which every abstract term is metaphorical. The characteristic of a truly scientific system of metaphors is that each term in its metaphorical use retains all the formal relations to the other terms of the system which it had in its original use. The method is then truly scientific— that is, not only a legitimate product of science, but capable of generating science in its turn.*" [28] p 227]

5. Einstein is famous for having devised and employed thoughts experiments that often featured metaphors. These thought experiments revealed new insights about gravity, acceleration, and spacetime physics among others [29]. For example, Einstein imagined scenarios in lifts and trains, falling of a building, or chasing

light beams to grasp essential features of the theory of relativity. To better understand the advanced mathematical underpinnings of general relativity, Einstein employed analogies similar to the rubber sheet model of spacetime:

"*Our problem can be illustrated with a nice analogy. I compare the space to a cloth floating (at rest) in the air, a certain part of which we can observe. This part is slightly curved similarly to a small section of a sphere's surface.*" [30 p 301]

6. Feynman often used metaphors as the first step to communicate difficult ideas in physics, for example the notion of energy [8]. Perhaps one of the most illustrative metaphors is the one in his Lectures on Physics that illustrates the particle nature of light:

"*Thus light is something like raindrops—each little lump is called a photon—and if the light is all one colour, all the 'raindrops' are the same size.*" [31 p 70]

In summary, the HPS perspective highlights the imaginative role of metaphors in scientific knowledge construction. Historically, metaphors have often served as aids to reasoning and, specifically, as aids to the imagination. By suggesting directions of inquiry, metaphors have guided many physicists in developing and refining scientific concepts.

4 How Can Metaphors Be Put to Good Use in Physics Education?

In the previous sections, we have gathered insights from PER and HPS to identify at least three crucial roles of metaphors in learning and doing physics, namely the conceptual, enactive, and imaginative one. According to the conceptual role, metaphors are conceptual mechanisms of embodied knowledge transfer. The enactive role highlights how metaphorical meaning can emerge when humans actively engage and interact with their environments. Finally, the imaginative role shows us how metaphors function as aids to imagination and can produce novel insights. Note that the three roles are not orthogonal but that there is overlap and that the different roles can be mutually constitutive. We now turn to instructional implications and suggest how the explicit use of metaphors can improve instructional practices in physics education.

4.1 Conceptual Metaphors as Embodied Mechanisms

Conceptual metaphors play a crucial role in abstract scientific understanding. Indeed, if our understanding of physics concepts is grounded in our bodies, teachers can tailor instruction to students' needs by grounding instructional activities in embodied sources [12]. Such grounding can take the form of choosing instructional metaphors with embodied sources or letting students perform concrete kinaesthetic activities that link to scientific concepts [32]. One promising implication of combining the imaginative and conceptual roles of metaphors is to consider metaphors as imaginary laboratories for conceptual change [33].

4.2 Enactive Metaphors as Figures of Actions

If we look at metaphors that come into existence through students' embodied actions, we can identify another opportunity of putting metaphors to good use in physics education, namely through metaphorical performances [10, 19]. Instructors can embed such performances in the environmental structure of science activities, for example, in technology-enhanced physics environments. Students can interact with responsive technologies in such environments and put metaphors to work by enacting physics concepts.

4.3 Metaphors as Aids to Imagination

In line with [1], we suggest using metaphors as an explicit part of instructional practices in the form of aids to the imagination. Such aids can take the form of tools that guide students to intentionally apply thought experiments or construct new metaphors when confronted with imaginative challenges [15]. Suppose we introduce metaphors as an object of instruction. In that case, we acknowledge that imagining is a universal process that students can apply in parallel with mathematical tools across different subjects and domains in physics.

5 Conclusion

The aim of this paper was first, to elucidate the different roles of metaphors in learning and doing physics from an embodied perspective and second, suggesting how explicit attention to metaphors can improve instructional practices in physics education. We took inspiration from PER and HPS to identify at least three important roles of metaphors. While the imaginative role of metaphors invites us to make imagination an explicit part of instructional practices, conceptual and enactive metaphors can support students' linking of abstract concepts and sensorimotor experiences from everyday life.

Once we understand these different roles of metaphors in learning and doing physics, we can show how they can be put to good use in instructional practices. Generally, metaphors prompt previous lived experiences and project similarities onto new, unfamiliar domains, but this transfer also induces expectations about the phenomena in question. In this way, metaphors can play a creative role that is often at the core of scientific inquiry: metaphors are flexible enough to generate new conceptual connections and stimulate idea generation—both in physics practice and physics education.

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Contribution of Inquiry-Based Physics Teaching and Learning in Initial Teacher Training

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Abstract Inquiry-based science education is an educational strategy in which students follow methods and practices like those carried out by scientists to build new knowledge. The objective of this research was to analyze the challenges posed by inquiry activities in the initial training of physics teachers. The present study was exploratory. The sample consisted of 49 students. The data were collected through the Mathematics and Science in Life questionnaire, MASCIL (Maaß K and Engeln K.: Report on the large-scale survey about inquiry-based learning and teaching in the European partner countries (2016).) The results showed that this strategy is rarely implemented in physics classes; However, when this occurs, both students and teachers benefit.

Keywords Inquiry-based teaching · Training teachers · High education · Physics learning

1 Introduction

The self-evaluation processes and the review of the scientific literature have revealed that it is necessary to incorporate different strategies for teacher training. For this reason, dynamic methodologies that involve students and teachers in inquiry tasks in real contexts are lacking. It is essential that, in the face of the new challenges of humanity, physics education also makes changes to achieve better performance of pre-service teachers in initial training. The focus of the research is to describe and analyze the potential of the inquiry-based physics teaching methodology.

Inquiry-Based Science Education (IBSE) is an educational approach wherein students follow methods and practices like those carried out by professional scientists to build knowledge [2]. The IBSE is a causal process that allows the student to formulate hypotheses and test them by contrasting them through systematic experimental activities and/or observations [3]. This approach emphasizes the participation

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and responsibility of students to discover the knowledge that is new to them. With this approach, students often carry out a self-directed learning process, part inductive and part deductive, doing experiments to investigate the relationships of at least one set of dependent and independent variables. ("Phases of inquiry-based learning: Definitions and the …—ScienceDirect") For its part, for several decades' science education has insisted that it is necessary to modify, or at least renew, science teaching methodologies. Likewise, this methodology has been important for the development of scientific thinking [4].

Several quantitative studies support the effectiveness of IBSE as a major approach in science education. For instance, [5] conducted a meta-analysis comparing inquiry with other forms of teaching, such as direct instruction or unaided discovery, and found that inquiry-based teaching resulted in better learning for students (mean effect size of $d = 0.30$). Likewise, a recent meta-analysis carried out by [6] incorporated studies that used a wide range of terms to describe inquiry-based learning (e.g., subject learning and constructivist teaching) with an overall mean effect size of 0.50 reported in favour of the IBSL approach when compared with traditional teaching.

Similarly, a research synthesis by [7] found a positive trend supporting the use of the IBSE over traditional teaching methods. In addition, it has been shown that the IBSE through the web can improve different inquiry skills, including the design and development of some experiments [8] Recent technological advances further increase the success of the application of inquiry-based learning [9, 10]. Educational policy management bodies around the world consider the IBSE to be a vital component in building a scientifically literate community [11].

Traditionally, inquiry has been understood as a way of teaching and learning science [4] (NAP 2000). Although this is an important application for that concept, the inquiry is much more fundamental. It encompasses not only the ability to participate in research, but also the understanding of research and how research results in scientific knowledge [4, 12].

Now, the Bachelor of Physics at the University of Antioquia has been concerned for quite some time about how the different curricular processes are developed. In this sense, the faculty has been making efforts to adapt traditional methods with advances from research in physical education. In particular, the internal and external self-assessment processes have revealed that it is necessary to incorporate some different strategies for the teaching and learning of physics. This has been possible thanks to both external and internal evaluations of the degree. This type of strategy must be consistent with the training purposes of the program. However, there is a lack of more flexible methodologies that involve students and teachers in inquiry tasks in real contexts. Therefore, and given the new challenges facing humanity, it is necessary for physical education to also make changes to achieve better performance and academic and professional success of teachers in initial training.

In this new context, a research project is proposed that brings together the best of national and international research in what has been called inquiry-based science education (IBSE). The reason for this choice is that recent studies have shown that inquiry learning, if well designed, can lead to better results than learning through more direct forms of teaching [6]. There are different domains where inquiry can have an impact. However, in science education domains it is especially effective in promoting learning [13]. These benefits can be mainly attributed to the fact that in inquiry learning students are expected to actively collect, process information, and build knowledge [5] This active participation in the learning process enhances the development of students' knowledge and skills [14].

In summary, the research presented provides compelling evidence that inquiry-based methods can be more effective than expository teaching methods. Its effectiveness has been demonstrated mainly in the learning outcomes assessed after the task, through subsequent tests of knowledge of a particular area. The way in which students evaluate their inquiry actions as well as the excellence of those products has received little attention [15].

The way in which students evaluate their inquiry actions as well as the excellence of those products has received little attention [15] The second conclusion that can be drawn is that the effectiveness of inquiry learning depends almost entirely on the availability of adequate guidance. Appropriate types of counselling cannot be determined based on existing reviews and meta-analyses. However, it is an important orientation to see what works and what does not work. This seems at least in part since counselling is often classified ad hoc based on the included studies. The use of an a priori classification based on a robust theoretical framework could be more fruitful and facilitate the interpretation of the findings. Ultimately, although some attention has been paid to possibly moderate effects related to the age of students, the relative effectiveness of different types of counselling for various age groups and areas has not yet been evaluated [15]. Therefore, we believe that there are opportunities for research and innovation.

1.1 Research Objectives

The objectives of this research are intended to:

To describe some dimensions of inquiry-based physics learning in the initial training of physics teachers.

Likewise, it was intended to analyze the relationship between different dimensions of inquiry and the type of physics course perceived by teachers in initial training.

2 Research Methodology

The present research was exploratory and was based on the analysis of the information provided by a group of students from a physics teacher training program. Both qualitative (coding) and quantitative (proportions; non-parametric statistics) techniques were used.

2.1 Participants

Data were collected from forty-nine students. The participants were students of the Licensure Program in Physics from the Faculty of Education of Universidad de Antioquia. To obtain representativeness, students from initial, intermediate, and final semesters were included among the participants.

The justification for this is that the subjects must be selected so that they can face the situations of inquiry presented to them and express their mental processes according to their level of training. Teachers of the program who guide different courses were also necessary so that the data allow analyzing the possible existence of an evolution of the mental processes associated with an increase in expertise and performance in the design of inquiry-based teaching activities.

In summary, the Licensure program will be attended, and data has been taken from (1) 3rd, 5th, and 10th-semester students and (2) physics teachers of this program whose experience and expertise in teaching the different physics courses.

2.2 Instruments

Quantitative data was collected through the Mathematics and Science in Life questionnaire, MASCIL [1, 16]. This Likert-type questionnaire consists of seventy-seven items. The items were distributed in six different dimensions or subscales with Cronbach's alpha ranging from 0.89 to 0.68. The instrument was administered to forty-nine of the Physics Degree of the Faculty of Education of the University of Antioquia. Information on its validity and consistency can be found in [1]. The information was made available on an online platform and then administered under the supervision of two researchers.

2.3 Procedure

Initially, The MASCIL questionnaire was administered among students and teachers [1]. The information through this instrument was collected using an online platform. Then, individual interviews were conducted to collect information about the students' learning data based on different experimental activities. Group interviews and discussions were videorecorded.

Additionally, these interviews were allocated in an artificial intelligence system, so that the information provided by each participant was immediately registered on a big data platform due to the high volume of content generated by participants' speeches.

3 Results

The results showed that the belief that students benefit from IBSL is significantly related to the routine use of IBSL in physics classes (see Table 1). On the other hand, orientation towards IBSL is also correlated with the belief that students benefit from IBSL. Consequently, this effect allows a greater disposition towards the IBSL, in both students and teachers.

3.1 Description of the Inquiry Activities Developed in Physics Class

Table 1 summarizes the outcomes of the present study. Data were not normally distributed and then, the median and the absolute deviation calculated from the median (MAD) were used instead of the mean values and standard deviations. The following subsets of variables extracted from the applied instrument were considered: Enjoyment, Inquiry Value, Self-concept, Inquiry Interest, Application, Practical Experiences, and Research.

A comparative analysis of two independent samples was performed for the subscales of inquiry according to gender. The values of the Me and the MAD values were similar for each subscale in the female gender (Me ± MAD = 3.0 ± 0.0), except for Practical experiences, and Research, which had an Me and MAD value = 2.0. In the case of the male gender, the Me and MAD values were similar for each of the subscales (Me ± MAD = 3.0 ± 0.0), except for Practical Experiences, and Research. In the Application subcategory, there was also a degree of variability. Precisely for this reason the minimums and maximums were included. On the other

Table 1 Description of the inquiry activities developed in physics class

Dimensions (Subset of variables)	Gender[a]		U Mann–Whitney	p-Value	Size effect (W)
	Female gender. (n = 16). Me ± MAD	Male gender. (n = 33). Me ± MAD			
Enjoyment	3.0 ± 0.0 [2.0; 3.0]	3.0 ± 0,0[1.0; 3.0]	247.0	0.584	0.081
Inquiry value	3.0 ± 0.0 [3.0; 3.0]	3.0 ± 0.0[1.0; 3.0]	232.0	0.157	0.205
Self-concept	3.0 ± 0.0[3.0; 3.0]	3.0 ± 0.0[1.0; 3.0]	232.0	0.157	0.205
Inquiry interest	3.0 ± 0.0[2.0; 3.0]	3.0 ± 0.0[1.0; 3.0]	239.5	0.368	0.131
Application	3.0 ± 1.0[1.0; 4.0]	3.0 ± 1,0[1.0; 4.0]	295.0	0.493	0.099
Practical experiences	2.0 ± 1.0[1.0; 4.0]	2.0 ± 0.0[1.0; 4.0]	289.0	0.584	0.080
Research	2.0 ± 1.0[1.0; 4.0]	2.0 ± 0.0[1.0; 4.0]	301.0	0.390	0.124

[a] Data are presented as median ± MAD [minimum value; maximum value]

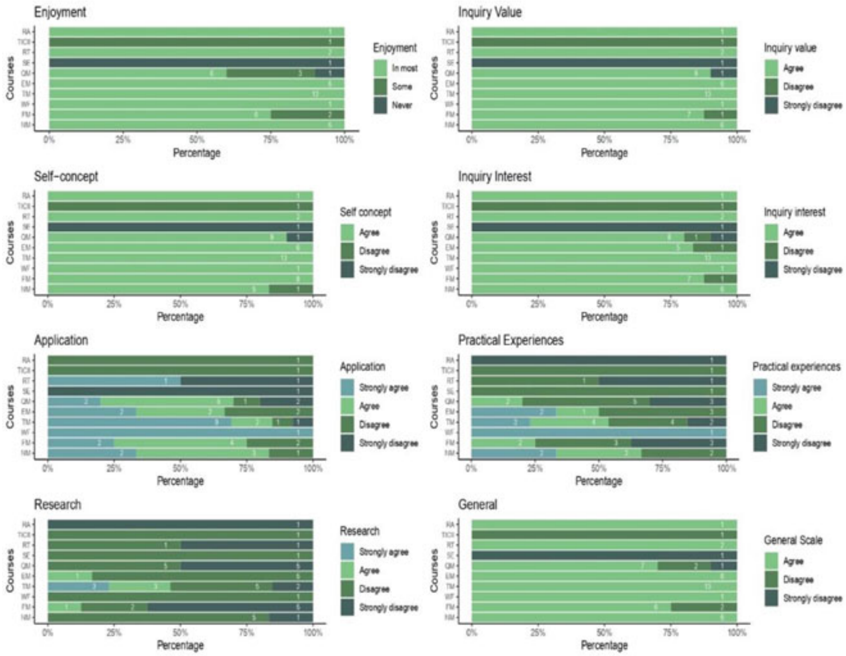
hand, for Practical Experience, variables present differences related to the course taken. To determine the magnitude of the information categories in relation to gender in physics courses, the Mann–Whitney test was used. Said Test showed that there were no statistically significant differences between gender and the different dimensions of inquiry ($U = 247.0$, $P = 0.584$), Table 1 shows the rest of the values. Since in principle no statistically significant differences were found, the Wilcoxon effect sizes were calculated, finding small values with slightly higher values for Inquiry Value, Self-concept, Inquiry Interest, and Research ($W = 0.205$, $W = 0.205$, $W = 0.131$, $W = 0.124$) respectively. This indicates that the female gender showed greater enjoyment in the inquiry activities than the male gender.

3.2 Relationship Between the Type of Course and the Previous Experiences with the Inquiry Activities Perceived by the Students

Relationship between the type of course and the previous experiences with the inquiry activities perceived by the students. To determine the relationship between the type of course and the previous experiences with the inquiry activities, a descriptive analysis was carried out with clustered bar graphs, in R and with the ggplot2 data visualization package (17).

In the grouped graphs of Fig. 1, it can be observed, the different courses, the absolute and relative frequencies, and the measurement scale that was used to assess the perception of the students of the inquiry activities in physics classes. The courses with the highest absolute frequency (fa) in relation to Enjoyment were thermodynamics, Newtonian mechanics, fluid mechanics, quantum mechanics, and electromagnetism ($fa = 13$, $fa = 6$, $fa = 6$, $fa = 6$, $fa = 6$) respectively. In this case, the students expressed greater enjoyment in the course of thermodynamics, wave physics, and electromagnetism.

The relative frequency for these courses was one hundred percent ($\% = 100\%$). Likewise, the students expressed less enjoyment in the physics didactics courses, followed by the quantum mechanics course. In relation to the Value of the inquiry, the subjects mainly agreed and gave high value to the inquiry in the courses analyzed. On the other hand, the study showed that the students have considerable agreement in relation to the Self-concept and the Interest that they give to the inquiry in the different courses. This occurs mainly in the courses of NM ($\% = 75\%$), FM ($\% = 100$), TM ($5 = 100$), EM ($\% = 100$), RT ($\% = 100$), RA ($\% = 100$). In relation to the subcategories of Application, Practical Experiences, and Research, it was where there was more variability. The students surveyed do not agree very much with the applications that were done or the implementations of the inquiry in physics classes, and in some cases, they strongly disagree according to the survey applied. For example, in the cases of didactics physics (SE) and relativity (RT). Likewise, there is considerable disagreement with the application of inquiry activities and practical



* Meaning for each acronym in the tables: NM: Newtonian Mechanics, FM: Fluid Mechanics, WF: Wave Physics, TM: Thermodynamics, EM: Electromagnetism, QM: quantum mechanics, SE: Science Education, RT: Relativity, TICII: Information technology and communication, RA: Real Analysis.

Fig. 1 Analysis of the relationship between different dimensions of inquiry and the type of physics course perceived by teachers in initial training. * Meaning for each acronym in the tables: NM, Newtonian Mechanics; FM, Fluid Mechanics; WF, Wave Physics; TM, Thermodynamics; EM, Electromagnetism; QM, quantum mechanics; SE, Science Education; RT, Relativity; TICII, Information technology and communication; RA, Real Analysis

activities that are carried out or not in the courses of quantum mechanics (QM) and fluid mechanics (FM). See Fig. 1.

4 Conclusions

The first objective of this research was to describe some dimensions of inquiry-based science learning in the training of physics teachers. According to the results obtained, it was found that learning by inquiry is related to the gender of the students. This could be evidenced by a marked correlation in categories such as 'Enjoy' and 'Research' where the female gender had a greater tendency to positively appreciate these activities. Likewise, the results showed that female students had a greater and better appreciation of the Self-concept dimension, which leads them to conclude that the inclusion of inquiry-based learning generates a positive self-concept on the part of these students. Of course, bearing in mind that this is an exploratory study, more replication is needed to be able to incorporate these results into the body of knowledge.

The second objective was to analyze the relationship between the type of course and the experience with the inquiry activities perceived by the students. The results showed that the students present some degree of variability between the subcategories considered and the courses, mainly when it comes to implementing the inquiry specifically in physics classes, it was found that in theoretical courses there is less possibility of application of this methodology, but perhaps where else should it be implemented to achieve greater interaction.

What can be observed in this exploratory research is that the type of course does have a direct relationship with the research activities that are carried out. The results showed that those courses that have a more theoretical component are less prone to carry out inquiry activities. In the Quantum Mechanics course, there is an opportunity to implement some inquiry activities to achieve a greater conceptual understanding of the topics; This could also be useful for the electromagnetism course. Although laboratory activities are normally carried out in this course, there would be added value if this methodology is considered. Consequently, the investigation allowed us to conclude that to implement the inquiry activities in the teaching and learning of physics, it is necessary to carry out an in-depth review of the processes that are traditionally carried out in these courses and develop a plan with clear purposes to be implemented.

Consistent with that, in a recent meta-analysis, Chernikova et al. (2020), simulation-based learning has been shown to offer a wide range of opportunities to practice complex skills in higher education and implement diverse types of scaffolding to facilitate effective learning.

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Astronomical Methods and the Terrestrial Climate: An Estimation of the Earth's Albedo Based on Self-Obtained Data

Simon F. Kraus

Abstract The recording and processing of self-recorded data is of great importance in astronomy and physics classes. However, within climate science, it is difficult to self-record relevant data. The article shows how learners can reproduce the method of albedo determination by astronomical observation, obtain their own data and evaluate them. The focus is on the usage of a simple recording system and the handling of scattered light, which is the major source of error. With the determination of the albedo of the Earth, the students learn to determine a quantity themselves, which is of elementary importance for the average surface temperature of the Earth, and which therefore also has a decisive influence on climate change.

Keywords Astronomy · Climate · Self-obtained data

1 Relevance of Self-Recorded Data

The educational relevance of self-recorded data in astronomy is widely emphasized in the literature. The main goals are to introduce students to scientific principles and methods and to data analysis [1]. LoPresto emphasizes the Nature of Science aspect of astronomy courses in general to this end [2], for which working with students' own data is particularly appropriate.

Especially in the field of climate science, it seems significant to be able to work with one's own data, since only analog experiments can be used here for the most part. It therefore seems highly reasonable to create a possibility to at least reproduce the methodical procedure and to generate own data from it. At this point, an attempt will be made to link astronomy with climate science by working with such self-recorded data.

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This approach provides the opportunity to measure an input variable to climate simulations that have a significant influence on the climate system (both in its absolute magnitude and in its relative changes under human and natural influence). For this purpose, the method presented here necessarily captures the albedo on large scales, as it is appropriate in the context of climate science. In addition, the large-scale method can be combined with local investigations and corresponding experiments, e.g., when the albedo of certain surface formations is determined on site by means of albedometers.

2 Significance of the Earth's Albedo

Even with classroom methods, a climate model can be developed which, although extremely simplified, already contains the radiation equilibrium as a central principle of the climate sciences. The starting point is the energy E_{in} irradiated by the sun:

$$E_{in} = G_{SC} \pi R_E^2 (1 - A) \tag{1}$$

In this, G_{SC} is the solar constant (which can indeed be assumed to be constant on the short time scales considered here, but which is variable on astronomical time scales), R_E is the Earth's radius, and A is the Earth's albedo. The Earth then emits this irradiated radiation, at a temperature T, again over its entire spherical surface:

$$E_{out} = 4\pi R_E^2 \sigma_{SB} T^4 \tag{2}$$

Therein σ_{SB} is the Stefan-Boltzmann constant. By equating and rearranging according to the temperature T, one now obtains the mean surface temperature of the Earth, which, however, does not yet consider the effect of the atmosphere:

$$T = \sqrt[4]{\frac{G_{SC}}{4\sigma_{SB}}(1 - A)} \tag{3}$$

In it the factor $(1 - A)$, i.e., the effect of the reflectance, expressed by the albedo A, remains. Typically, for a calculation, a constant value of 0.3 is now assumed for A to obtain an appropriate value for the temperature. However, it is widely ignored how this value is to be determined at all and which fluctuations it may be subject to. It should be noted that this model, even in its simplified form, still contains an inherent error. The starting point is the atmosphere-less body of the Earth, but a value for the albedo of 0.3 already corresponds to the mean albedo of the planet, in which, however, both the surface properties and the clouds and aerosols in the atmosphere were already included.

The significance of the albedo should not be underestimated, not only in such highly simplified climate models, but also in real climate models. For example, the

IPCC report of 2013 explicitly identifies surface albedo among the radiative forcings [3]. Anthropogenically induced changes to this quantity result here from land use and from inputs of dark carbon compounds on snow and ice surfaces, which significantly reduce their reflectivity and thus lead to their increased warming.

However, this is by no means the only contribution to the global mean temperatures by the albedo, nor is it the most significant. In addition, there are, for example, the contrails of airplanes, which contribute to a higher degree of coverage by high cirrus clouds. However, the interactions between the aerosols and the radiation directly and additionally indirectly, via the cloud formation at the aerosols, are clearly more relevant for the climate. The latter two effects lead to a significant cooling effect, the exact amount of which, however, cannot be precisely determined at present.

3 Principles of Albedo Determination

3.1 Brief Outline of the Classical Methods

An effect that is fundamental to the method of albedo determination of the Earth presented here has been known since earliest times, and was almost correctly interpreted for the first time by Leonardo da Vinci. When the moon stands in the sky as a crescent, the part of the Moon's surface which is currently not illuminated by sunlight can nevertheless be recognized quite well. Da Vinci was the first to attribute this effect to the sunlight reflected from the Earth, which reaches the Moon's surface and is reflected a second time there. In the following centuries it became gradually clear that this light reflected by the Earth contains information about the nature of the Earth's surface and its atmosphere and that this information can be recovered and evaluated. Alexander von Humboldt, for example, described the change in the colour of the reflected light caused by the forests of South America in his work Cosmos [4]:

> Lambert made the remarkable observation (14th of February, 1774) of a change of the ashcolored moonlight into an olive green color, bordering upon yellow. "The Moon, which then stood vertically over the Atlantic Ocean, received upon its night side the green terrestrial light, which is reflected toward her when the sky is clear by the forest districts of South America."!

One of the first successful efforts to determine the value for the Earth's albedo also quantitatively goes back to André Danjon [5, 6]. For his measurements in the 1920 and 1930s, he constructed a so-called cat's eye photometer, with which the image of an object in the optical path of a telescope can be doubled. This is done by means of two prisms, which can be rotated against each other and thus also allow free positioning of the doubled image. A variable aperture additionally permits to adjust the brightness of the doubled image. The objective of the procedure is to compare the intensities (or brightness's) of the bright (illuminated by sunlight) and the dark part (illuminated by Earthshine) of the Moon. To do this, the bright side of the doubled image is moved next to the Earthshine side of the original image. By closing the aperture, the brightness of the crescent moon in the double image is now adjusted to the brightness of the ashen moonlight in the original image. By measuring the aperture, one gets the intensity in relation to the original image. The procedure itself requires further steps which, however, will not be reproduced in detail here (see Kraus [7] instead).

3.2 Simple Realization by Means of Modern Camera Technology

Today, the realization of a method based on Danjon's technique can be done without doubling the image within a telescope. Instead, CCD cameras can be used to quantitatively measure and compare the intensities of both sides of the Moon's crescent. The data acquisition is done, for the case presented here, with a simple Newtonian telescope—focal length 1000 mm, aperture 200 mm. The camera is a commercially available and unmodified DSLR.

Since the dynamic range of no camera can provide usable data of both areas in one image simultaneously, the images must be taken separately. For this purpose, it is necessary that the camera in use provides a signal that is linear to the exposure time, at least for the selected saturation range of the CCD chip. This condition is fulfilled (at least for the level of accuracy intended here) for astronomical as well as for DSLR cameras. With a DSLR, however, it is important to note that recording must be done in a raw data format, as saving in a format like JPEG will make the data unusable. While each camera initially only counts photons and calculates a value for the brightness from this, real intensities are required for further evaluation. These are obtained by dividing the brightness μ given by the camera by the exposure time t_{exp}.

The albedo is then again, the ratio of these measured intensities:

$$A \propto \frac{I_{Earthshine}}{I_{Moonlight}} \tag{4}$$

In order to calculate the albedo on the basis of this proportionality, further quantities are necessary. These include three so-called phase functions, which describe the brightness profile of the relevant bodies or surfaces when viewed from different angles. The phase function $f_{E,L}(\beta)$ describes the reflective properties of the Earth, which can be described as a Lambertian emitter. The other phase functions $f_{ml}(\theta)$ and $f_{es}(\theta_0)$ refer to the lunar surface. Since the angle at which the earth appears from the moon is quite small, the value of f_{es} can be set equal to one. Thus, the phase function of the moon remains, which cannot be derived analytically but has to be obtained empirically [8]. We take this phase function as given here. The equation for the albedo gets the form (for the details of the derivation, see Kraus [7]):

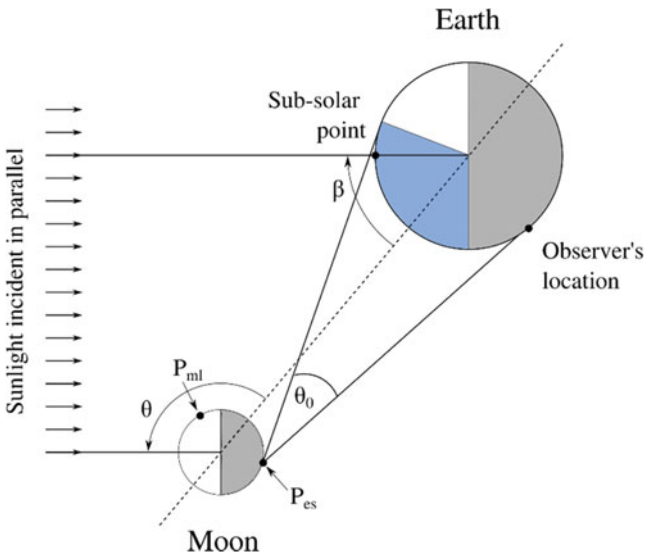

Fig. 1 Geometric relations, significant angles and quantities for an exemplary alignment of the celestial bodies involved

$$A_{eff} = \frac{3}{2}\frac{1}{f_{E,L}(\beta)}\frac{I_{es}\,p_{ml}\,f_{ml}(\theta)}{I_{ml}\,p_{es}\,f_{es}(\theta_0)}\left(\frac{R_{ES}}{R_E}\right)^2\left(\frac{R_{EM}}{R_{MS}}\right)^2 \tag{5}$$

The other quantities are the reflectance of the surfaces of the Moon p_{ml} and p_{es} (which are assumed to be identical), where the measurements take place. R_e is the Earth radius, R_{ES}, R_{EM} and R_{MS} are the Earth-Sun, Earth-Moon and Moon-Sun distances, which are squared to represent the geometric relations (Fig. 1).

3.3 Corrections for Scattered Light

The biggest obstacle in performing this method is scattered light, which is difficult to handle due to the enormous brightness of the Moon. In any other astronomical observation, one strives to avoid the bright Moon as much as possible, whether by choosing appropriate observation times or maximizing the angular distance of the observed area from the Moon. Here now the Earth's satellite itself is the target of our measurement. As can be seen in Fig. 2, the scattered light emanates from the sunlit side of the Moon, extends over the entire field of view of the camera, and thus also includes the area of the Earthshine. Consequently, the intensity of the scattered light must be subtracted from the intensity readings at Mare Humorum. For this purpose, a method is used here, which is also applied in professional contexts.

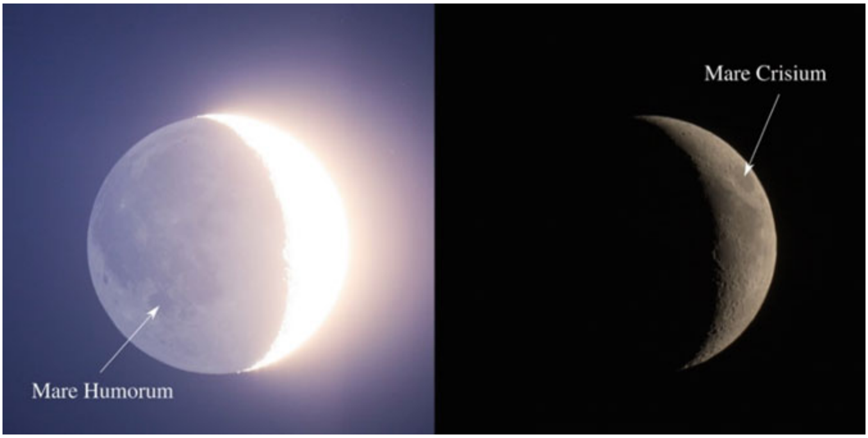

Fig. 2 Sample images showing the Mare Humorum and Mare Crisium, where the intensity determinations were made. Note the strong influence of the scattered light in the image of the Earthshine (left part of the image)

To determine the extent of scattered light at this point, further intensity determinations are made at some distance from the moon. For this purpose, a cone is stretched out whose origin lies in the middle of the terminator (i.e., the day-night boundary) and from there passes the Mare Humorum on both sides. Within this cone (the area shaded in gray in Fig. 3) the intensities and simultaneously the x–y coordinates within the image are recorded several times for each of these measurements.

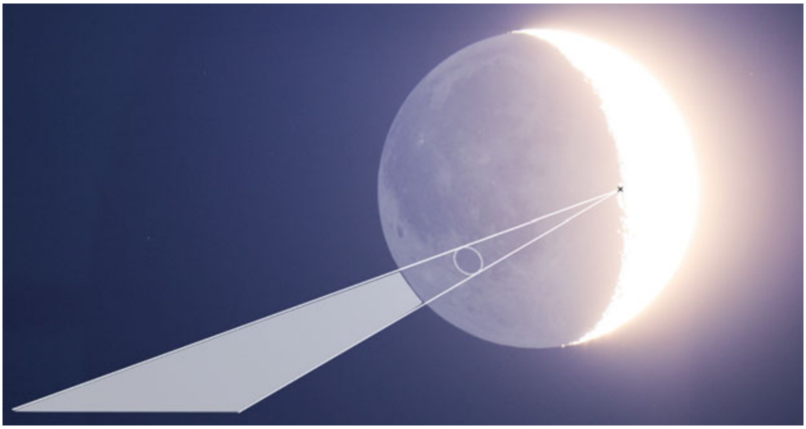

Fig. 3 Measurement of the background intensity caused by the scattered light of the bright crescent. The intensity increases somewhat linearly toward the center of the Moon. This allows to extrapolate the background intensity at Mare Humorum

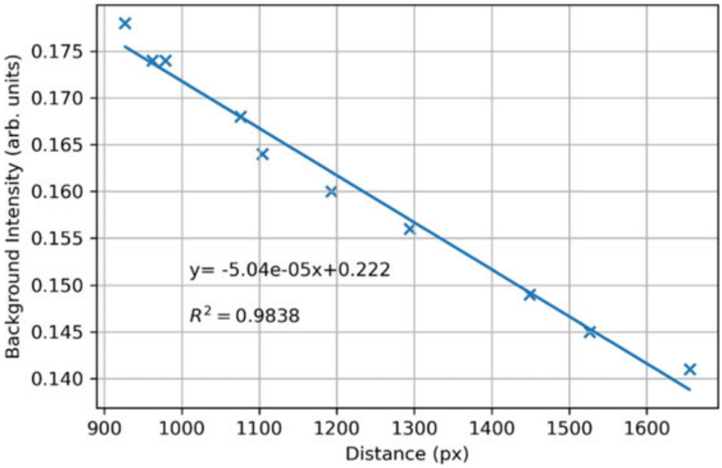

Fig. 4 Measurement of the background intensity caused by the scattered light of the bright crescent. The intensity increases somewhat linearly toward the center of the Moon. This allows to extrapolate the background intensity at Mare Humorum

It can be seen that the intensity decreases linearly with increasing radial distance from the lunar disk (Fig. 4). Using the coordinates of the origin of the cone, it is now possible to infer the intensity within the Mare Humorum.

Table 1 shows the raw data obtained from three images each for the Moonlight and Earthlight sides, i.e., for Mare Humorum and Mare Crisium. In this, the exposure times deviating by a factor of 500 become apparent, which ultimately lead to the differences in the—still uncorrected—intensities of a factor of 1000. The corrections for the scattered light are made based on Table 2, in which in column μ_{bgr} the brightness of the background for the Mare Humorum was determined by means of the method described above. The ratio of the total brightness to the background brightness shows a signal-to-noise ratio of just under 1.3, which indicates sufficient data quality. Based on Eq. 5 and using current values for the distances of the celestial bodies as well as the value for the phase function of the moon, an albedo of $A = 0.22 \pm 0.3$ results for the values used here.

To be able to evaluate this result, which is clearly below the expected value of 0.3, a look at the alignment of the celestial bodies is necessary in each case. The light, which reaches the otherwise dark side of the Moon, originates from the area marked in blue in Fig. 1. Due to the constant rotation and revolution of the Moon and the Earth, the corresponding area on the Earth's surface shifts. At the time of the data recording, the eastern Pacific, including the western USA lay in the center of this area. And at the same time, images from the GOES-West weather satellite show that at the corresponding time, cloud cover over the ocean was low. Since the albedo of open water surfaces is relatively small ($0.05 \leq A_{Water} \leq 0.22$, depending on the angle of observation), the result is thus in an accurate range.

Table 1 Raw data of a measurement series of three images each for the sunlit (moonlight) and the Earthshine side

	Image no	$t_{\exp}$	$\overline{\mu}$(arb. units)	I_{norm}(arb. units)
Moonlight	1	0.01	0.512	51.200
	2	0.01	0.512	51.200
	3	0.01	0.515	51.500
Earthshine	4	5.00	0.257	0.051
	5	5.00	0.256	0.051
	6	5.00	0.252	0.050

Table 2 The extrapolated background intensity must be subtracted from the measured intensities μ. The quality of the images can be assessed via the SNR $\left(\frac{\overline{\mu}}{\overline{\mu}_{bgr}}\right)$

Image no	$\overline{\mu}$(arb. units)	$\overline{\mu}_{bgr}$(arb. units)	$\frac{\overline{\mu}}{\overline{\mu}_{bgr}}$
4	0.257	0.195	1.32
5	0.256	0.205	1.25
6	0.252	0.199	1.27

3.4 Possible Alternatives for the Implementation

For the sample measurements used here, the observations were made in two lunar maria. This is necessary because the surface albedo of both areas must be the same (alternatively, knowledge of the absolute values for the reflectance of both surfaces would also be sufficient).

In high-precision observations, by contrast, measurements are made in the highlands of the Moon. These offer the advantage of being present close to the western and eastern lunar limb, whereas the maria do not entirely reach the eastern limb. This results in an extension of the observation timeframes over a wider range of lunar phases. Even more significant is the increase in signal-to-noise ratio since the highlands are much brighter overall. However, it is known that the surface albedo of the highlands is much more inhomogeneous than that of the Maria, so that the same reflectivity for p_{ml} and p_{es} cannot be assumed for arbitrary patches.

A very important step for the further improvement of the simple measurement technique, is the handling of the scattered light. Even for professional telescopes, this is the most challenging issue. While the correction procedure used here is based on scientific methods, optimization of the instruments themselves is still lacking. Figure 5 shows a contrast-enhanced and inverted version of a sample image, clearly showing the inhomogeneity of the scattered light as it occurs in some images. It is suspected that these are reflections of the very bright Moonlight (note the advanced phase of the moon) off the secondary mirror rims and struts of the telescope. While in principle it can be assumed that such reflections occur less often with refracting telescopes, this could not be confirmed so far for the instruments available for the author (however, the observation circumstances were not comparable with each other).

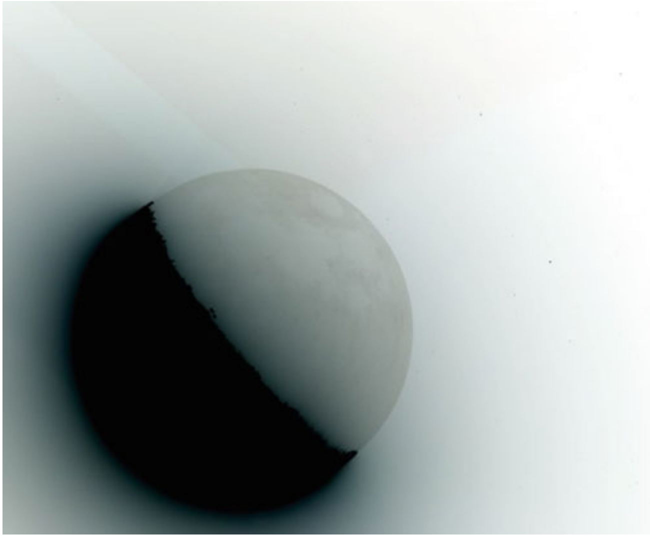

Fig. 5 Inverted and contrast enhanced image of an earthshine measurement. The scattered light shows clear deviations from a simple linear pattern here

Even without the presence of obvious strong reflections, deviations from the expected linear relations between the scattered light intensity and the distance from the center of the crescent moon can be observed in some cases (Fig. 6). However, since this intensity can only be determined outside the lunar disk, it is not readily possible to extrapolate the intensity progression to the Earthshine intensity measurement patches in question. Clarification of the actual course could be achieved by a significant increase in the number of scattered light measurements within the image. These, like all evaluation steps, have been performed manually up to now. An automated or partially automated evaluation procedure could also provide a further learning opportunity in the field of information technology and could be implemented with reasonable effort using suitable program libraries in the Python programming language.

4 Conclusions

The simplified method presented here seems to be suitable to understand the determination of a central variable for the terrestrial climate itself. It is not about the highest possible precision, but about the understanding of the method as well as its potential to provide global, highly precise, and long-term measured values. It thus offers the opportunity to develop an understanding of the necessity, the importance, and the difficulties of the underlying method, where previously only constants were provided for a calculation.

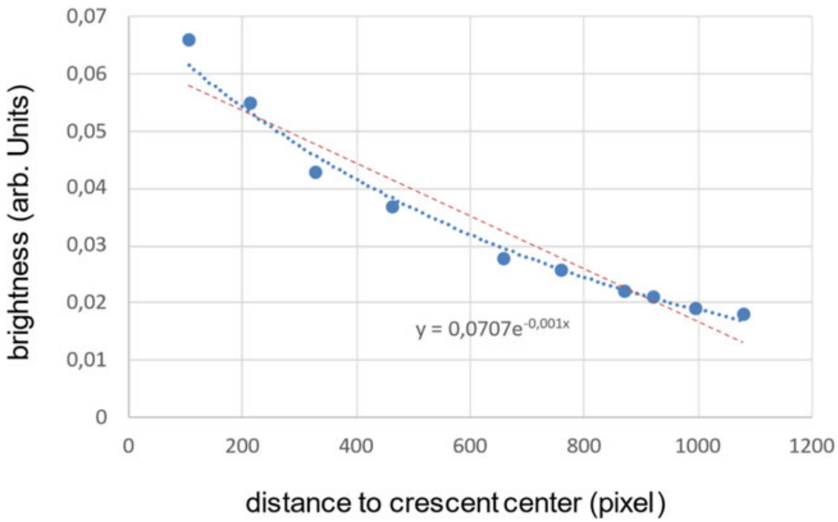

Fig. 6 Background brightness as a function of the distance to the center of the crescent deviating from a linear relation

Besides methods of remote sensing by satellites, the method of albedo determination out of the Earthshine is still an essential method of modern climate science. The method thus establishes a link between astronomical methods and climate sciences. This connection is implicitly, via the elementary solar-terrestrial relations, always the basis of every climate model, but this close connection is not always visible when it comes to an implementation in educational contexts.

Regardless of the specific content, the method also offers the opportunity to learn how to deal with erroneous data, how to evaluate the quality of self-obtained values, and correction procedures for erroneous variables.

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Spacetime Globe: A Teaching Proposal for the Didactic of Special Relativity

Alessio Mattia Leonardi, Settimio Mobilio, and Claudio Fazio

Abstract Special Relativity acquaints students with Modern Physics, the significance of which is growing within Italian high schools. To face the difficulties both teachers and students encounter, different solutions have been developed. We present an experimentation regarding the teaching of Special Relativity we carried out in last year classes of High Schools oriented to scientific studies. In this project a mechanical instrument was used which allows to explain and show Lorentz transformations, exploring by hand the effects of a change of reference frame. Teachers and students were able to deal "by eye" with relativistic phenomena.

Keywords Special relativity · Spacetime diagrams · Didactics of physics

1 Introduction

Special Relativity is a milestone in Physics but its learning and teaching still suffers and difficulties from students and teachers persist at secondary and higher education. Different authors [1–3] analysed the impact of the previous knowledge in learning Special Relativity, showing that the misunderstanding of the structure of Classical Mechanics is a huge obstacle to its comprehension [4].

Problems are rooted in the concept of reference frame [4–7] which is not held by students [4] but it is the starting point for the study of Special Relativity [3–5, 8]. Panse et al. [9] found 7 misconceptions about reference frames: students do not know what constitutes it [10] nor they think in terms of it [6].

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Full descriptions of the alternative frameworks in Special Relativity have been re-ported in literature by Aslanides [11], Alstein et al. [7] and Prado et al. [12]. Regard-less of the level of instruction, students have difficulties in understanding and internalising the relevant consequences of Special Relativity [2, 3, 5, 8, 13–15]. As there is no chance to experiment relativistic phenomena, students appeal to their common sensory experience [2]. This increases the conflict between its outcomes and their intuition. Many authors noticed that students adopt the ground reference frame [2, 6, 7, 16–19] as the preferred one with an absolute sense. The misconception observed by Saltiel and Malgrange [6] between a real and an apparent motion is more emphasised leading students to consider time dilation and length contraction as an optical illusion [1, 2, 16, 18, 20] as well as asymmetric phenomena [11].

To face these difficulties, different strategies emerged [7, 12, 21]; among them one has a great resonance in the literature: the geometrical approach based on the spacetime diagrams acquired from Minkowski's heritage [22] which shows the existence of an absolute spacetime. Relativistic phenomena imply necessarily the existence of a four-dimensional spacetime [23] and Minkowski spacetime diagrams efficiently convey their real nature, as the spacetime effects arise from a non-Euclidean geometry. The kinematics of Special Relativity can be easily derived [24] from Minkowski diagrams, together with Lorentz transformations and invariant quantities. Minkowski's substantivalist view of spacetime has numerous didactic implications [25] and his geometry paves the way to General Relativity's concepts. Some problems related to the equivalence principle [26] or to the transition from Special Relativity to the General one [27] can be solved thanks to four-dimensional spacetime.

The construction of Minkowski diagrams is a big request for a high-school student. Consequently, educational attempts were made in order to simplify their construction [28–30]. In his project involving students of the last year of high school, Moutet [31] used a didactic reconstruction of Minkowski spacetime diagrams with promising results in terms of students' understanding and assimilation of the concepts of Special Relativity. He also pointed out the need for a complete formation for teachers about the use of these diagrams. A greater importance takes on the proposal of Taylor and Wheeler [32] that relies entirely upon the geometry of spacetime and invariant quantities. This book was the keystone of the experimentation carried out by De Ambrosis and Levrini [26] among Italian high-school teachers to evaluate the possibility of a didactic project based on Taylor and Wheeler's approach. Despite some initial resistance, teachers agreed on its reliance and relevance [26].

Changing the didactic practice is an urgency whose relevance is increasing more and more [27] and this has been confirmed by our preliminary analysis [33]. Thus, recently different authors began to develop curricula for both high-school and university teaching of Special Relativity based on spacetime diagrams, highlighting strengths and critical issues. In 2001, Berenguer and Selles [27] proposed a curriculum for the bachelor's degree in Physics based on Minkowski diagrams with positive outcomes related to a greater understanding and ability of students to represent relativistic effects visually and graphically. Liu and Perera [24] showed that Minkowski diagrams can be used to illustrate paradoxes efficiently and that spacetime diagrams help students to visualise situations, facilitating qualitative reasoning. The turn into a quantitative one requires only a few steps forward. Cayul and Arriassecq [34] investigated the use of Minkowski spacetime diagrams to evaluate simultaneity of two events among different observers in relative motion. They found no difficulties about the use of spacetime diagrams but in performing numerical calculations and in the correct use of algebraic equations to determine the simultaneity of events. Prado et al. [12] developed their inquiry with a teaching proposal for high schools based on Minkowski spacetime diagrams in forms of event diagrams [35] to visualise and to ex-plain qualitatively and quantitatively relativistic phenomena. They tested this strategy with students of a high school in a Spanish town with promising results.

2 Spacetime Globe

As relativistic effects are the result of the change of reference frames, in our experimentation we looked for a solution which could allow students to perceive this feature. Thus, we used the spacetime globe (see Fig. 1), an instrument which reproduces a bi-dimensional Minkowski spacetime diagram [36, 37] whose time ct and spatial x axes are depicted on the Plexiglas sheet with a grid printed on. Each die represents an event whose coordinates are identified using the grid: the property of this tool is that the dice can be moved along the hyperbolas-shaped tracks engraved over the base acting on the bars.

To understand how the spacetime works, consider the following case study: two different observers, a red man and a blue cat, in relative motion with speed $v = c/3$ and a box catching fire at a certain point in spacetime. The situation can be described according to the two observers' different points of view as shown in Figs. 2 and 3.

In Fig. 2 the red man's reference frame is adopted. The cat is moving with respect to him with speed $v = c/3$ while the box is 0.5 m distant from him, catching fire after $4.75/c$ second. The box's event is a certain spacetime point having coordinates $A = (x_A, ct_A) = (0.5, 4.75)$. The spacetime globe is depicting the point of view of

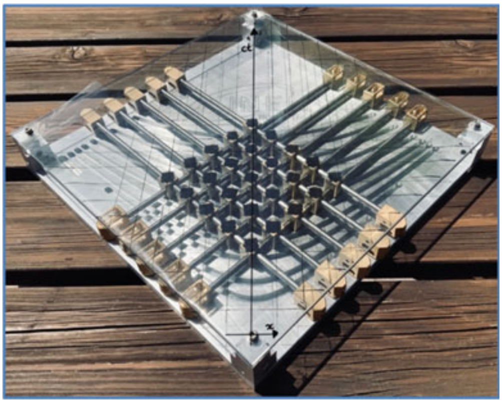

Fig. 1 Our spacetime globe

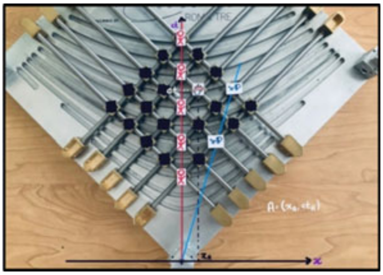

Fig. 2 The red man's point of view on the spacetime globe

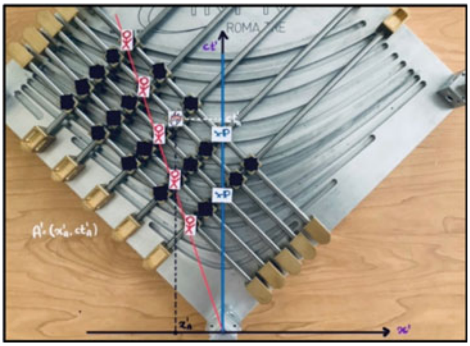

Fig. 3 The blue cat's point of view on the spacetime globe

the red man. Indeed, his worldline is a vertical line in $x = 0$, thus laying over the time axis, as he will see at himself as stationary, in the centre of his reference frame. Then according to him at time $t_A = 4.75/c$ s a burning box appears instantaneously and then disappears. Finally, the red man is seeing the cat moving with speed $v = c/3$, thus its worldline is $t = (3/c)x$.

Conversely in Fig. 3, the blue cat's reference frame is adopted, thanks to the mechanical properties of the spacetime globe. Indeed, we can manually act over the bars of the instrument, moving the dice until we reach the configuration shown in Fig. 3: now the blue cat's worldline is vertical $x' = 0$, meaning that it is at rest with respect to itself. Then according to the principle of relativity, the cat sees the red man moving away from it with the same speed but in the opposite direction. The cat's worldline is $t' = -(3/c)x'$: we can verify it, by checking the equivalence of the angle between the two worldlines in Figs. 2 and 3.

In the same way we can see how event A is transformed and measuring its coordinates on the spacetime globe we find that $A' = (-1.13, 4.88)$. The correct value from Lorentz transformations is $A' \simeq (-1.15, 4.86)$.

Thus, with a simple action on the bars of the instruments we can change the reference frame from one observer to another, getting the same qualitative and quantitative results one obtains applying Lorentz transformations. This is a consequence of the hyperbolas-shaped tracks: being hyperbolas the geometrical locus of a Lorentz transformation, we demonstrated [33] that each time the reference frame is changed, the position of each die is mapped into its transformed under Lorentz transformation.

With this approach many relativistic phenomena can be investigated as a consequence of the change between reference frames: loss of simultaneity, time dilation, length contraction, relativistic addition of velocities, invariance of speed's light and of mass, and Doppler effect [37].

3 Experimentation

To use the spacetime globe as a didactic tool we structured a project, aimed by the feedback of some high-school teachers [33] interested in our tool. Our pilot experimentation focused over the themes of greatest interest from a scholastic point of view within two lessons two hours long:

- first lecture: we started with a brief recap about the relativity of motion in Classical Dynamics. After explaining the connection between reference frame and point of view, we introduced Einstein's principles of Special Relativity and Lorentz transformations. Forthwith we presented the spacetime globe as an instrument reproducing a Minkowski diagram: we explained what is a spacetime diagram, how observers are identified and how we can understand observers' state of motion looking to worldlines. Finally, loss of simultaneity and time dilation were shown;
- second lecture: it started with a recap of the main contents of the previous one. Then other relativistic phenomena are faced, namely the length contraction with the Ladder paradox in its version with a train and a tunnel and the relativistic addition of velocities. Finally, it is shown that the light's speed is preserved under Lorentz transformation.

The *leitmotif* throughout all the lectures was that Special Relativity deals with how events appear to different observers depending on their state of motion. Independently from Dimitriadi and Halkia [16], we replaced the idea of "changing a reference frame" with "adopting a different point of view".

The two lectures were held during spring 2021, with 5 different groups attending the last year in 3 different high schools of Rome. Three groups took the lectures in presence, while the other ones remotely. Four out of these five groups already attended scholastic lessons on Relativity. Thus, for most of them our experimentation should be considered as an integration and a review. We finally structured two questionnaires for the students:

- a pre-test was given at the beginning of the first lecture. It has twelve questions about Classical Mechanics concepts and Galilean Relativity; it is organised with seven multiple-choice questions and five open-questions. We also included three other questions about students' previous knowledge of Special Relativity. Four multiple-choice questions were taken from the Relativity Concept Inventory [38]. We also looked to the Force Concept Inventory [39];
- a post-test was given at the end of the second lecture. It has thirteen questions about the Special Relativity concepts investigated during the lectures. It is organised with

nine multiple-choice questions (six of them were taken from [38]) and four open questions.

The two tests address different questions as they are meant to investigate the understanding of different concepts. Only a pair of questions are similar, namely those referring to simultaneity between two events in a classical and relativistic scenario as seen from different reference frames.

The total number of the answers to the pre-test were 95 with respect to the 85 answers to the post-test, with 77 individuals taking both tests.

4 Result

To understand if our questionnaires were well calibrated, we carried out a quantitative analysis of the multiple-choice questions of both the tests, using a set of statistical indexes from classical test theory that estimate the discrimination and consistency of a questionnaire [38, 40]. Discrimination is the capability of a test to quantify the understanding of a topic and its measure is given by the discrimination index D_i as defined in Eq. (2). Consistency is the ability of each question to measure the same broad understanding.

The analysed indexes are:

- indexes who measure a feature of the single questions:
  - the *difficulty* P_i for each question

$$P_i = \frac{N_i}{N}, \tag{1}$$

    defined as the ratio between the number N_i of the correct answers to the i-th question and the total amount N of the answers to that question;
  - the discrimination index D_i for each question

$$D_i = \frac{N_H - N_B}{N/4} \tag{2}$$

    is a normalised difference between the correct answers to a question i in the top quartile N_H and the bottom quartile N_B of students. It is a measure of the capability of a question of distinguishing students with high result from those with low result;
  - the point biserial coefficient r_{pbi} for each question

$$r_{pbi} = \frac{\langle X_{r,i} \rangle - \langle X_{w,i} \rangle}{\sigma_x} \sqrt{P_i(1 - P_i)}. \tag{3}$$

Here, $\langle X_{r,i} \rangle$ is the mean value of the total score of those students who correctly answered to question i, $\langle X_{w,i} \rangle$ is the mean value of the total score of those students who incorrectly answered to question i, σ_x is the standard deviation of the total scores while P_i is the value of difficulty index for question i. This index measures the correlation between each item score and the total score for the inventory.

However, to get an overall view about these three indexes we evaluated their mean value (as in Aslanides and Savage [38]): thus, we also have a mean difficulty index, a mean discrimination index and a mean point biserial coefficient. The associated uncertainty is given by the standard error of the mean while the statistical uncertainty associated with the values of each index for each question is given by the standard deviation.

- indexes who evaluate the test as a whole:
  - the Kuder-Richardson reliability index r_{test} or KR-20 index

$$r_{test} = \frac{K}{K-1}\left(1 - \frac{\sum_i P_i(1-P_i)}{\sigma_x^2}\right); \tag{4}$$

K is the number of questions, P_i is the difficulty value for the i-th question and σ_x is the standard deviation of the total scores. It measures how the questions are correlated with each other, namely the internal consistency of the test. As we associated to the value of P_i an uncertainty, we can give to Kuder-Richardson reliability index an uncertainty that can be derived using standard theory of errors:

$$\sigma_{r_{test}} = \frac{K}{K-1}\frac{\sigma_P}{\sigma_x^2}\sqrt{\sum_i \left(1 - 2\left(P_i - P_i^2\right)\right)\left(P_i - P_i^2\right)^2}; \tag{5}$$

  - the Ferguson's delta δ

$$\delta = \frac{N^2 - \sum_i f_i^2}{N^2 - N^2/(K+1)}. \tag{6}$$

Here, N is the total number of the students answering to the test, K is the number of the questions and f_i is the number of the students with a total score i. It is a measure of the distribution of the students' scores over all the possible values. Greater the broadness, better is the capability of the test to discriminate among students at different levels.

Now we present the analysis of the results for the multiple-choice questions of both the tests.

4.1 Pre-test

The pre-test has seven multiple-choice questions; the result of the analysis is shown in two tables: Table 1 displays the values for the first three indexes (P_i, D_i and r_{pbi}) while Table 2 summarises the mean values for each index of Table 1 together with the value of the reliability index and the Ferguson's delta.

From Table 2 we see that only the reliability index is out of range while the other ones are inside the desired values. The mean discrimination index and the Ferguson's delta are just above the threshold. To complete the analysis, we plot in Fig. 4 the values of the difficulty index, the discrimination index and the point biserial coefficient index for each question with their threshold values.

From the mean difficulty index it seems that the difficulty of the pre-test is acceptable as a value of $\langle P \rangle = 0.56 \pm 0.08$ indicates that on average the questions are not either too difficult or easy. However, this is not true for all the items of the inventory. Figure 4 suggests that question 3, 4 and 8 may be too difficult, question 1 and 7 a little bit easier than the other ones while question 11 is too easy. A reasonable value for the difficulty index should be 0.5 for all the items [40].

Questions 3 and 4 regard the path followed by a ball thrown out of a moving train (see Fig. 5). Question 3 got random answers being equally distributed among the three choices. Answers to question 4 are in proportion of ~2/3 of wrong to ~1/3 right: we guess that students may be misled by thinking of following the ball. As the train goes away from the object, while it is falling, it may appear to Giulia that path

Table 1 Value of the difficulty index, discrimination index and point biserial coefficient of the pre-test. Sample size $N = 95$ students

Item	Difficulty index	Discrimination index	Point biserial coefficient
Question 1	0.7 ± 0.2	0.2 ± 0.1	0.44 ± 0.06
Question 3	0.3 ± 0.2	0.4 ± 0.1	0.54 ± 0.06
Question 4	0.3 ± 0.2	0.4 ± 0.1	0.40 ± 0.06
Question 7	0.6 ± 0.2	0.4 ± 0.1	0.44 ± 0.06
Question 8	0.5 ± 0.2	0.4 ± 0.1	0.47 ± 0.06
Question 10	0.6 ± 0.2	0.2 ± 0.1	0.50 ± 0.06
Question 11	0.9 ± 0.2	0.1 ± 0.1	0.34 ± 0.06

Table 2 Pre-test statistics. Sample size $N = 95$ students. The desired values are taken from [40]

Test statistics	Pre-test values	Desired values
Mean difficulty index	0.56 ± 0.08	[0.3, 0.9]
Mean discrimination index	0.31 ± 0.04	>0.3
Mean point biserial coefficient	0.45 ± 0.02	>0.2
Reliability index	0.35 ± 0.05	>0.7
Ferguson's delta	0.91	>0.9

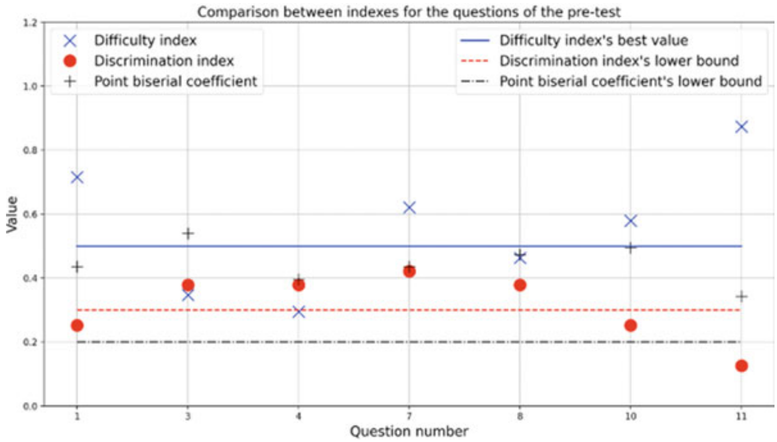

Fig. 4 Comparison between indexes difficulty (blue ×), discrimination (red ∘) and point biserial coefficient (black +) of the pre-test. The corresponding lower bound is the blue solid line (−), the red dashed line (−−) and the black dash-dot line (−.)

(a) is the correct path. We address that for both the questions the idea of throwing the object out of the train could have deceived the students.

Another consideration concerns questions 10 and 11 which ask the same question according to two different observers (see Fig. 6). Students seem quite confident that inside the train (question 11) the balls hit the ground at the same time. But it is not the same for question 10, where an external observer is considered. The difficulty index decreases showing that for many students simultaneity is not preserved: ~1/3 of the students think that the balls do not hit the ground at the same time.

To evaluate the discrimination index, we used students' score to our multiple-choice test as the internal criterion to gather them [40]. We created four groups: the top quartile includes students with score $\geq 6/7$, two middle groups for students with score $[5/7; 6/7)$ and $[3/7; 4/7]$ and the bottom quartile for students with score $\leq 2/7$. From Table 4, the mean value of the discrimination index $\langle D \rangle = 0.31 \pm 0.04$ is just above the desired value of 0.3. A low value of the mean discrimination index may suggest that on average our items are thinly able to distinguish the high-achieving students from the low-achieving ones. The discrimination indices of the questions

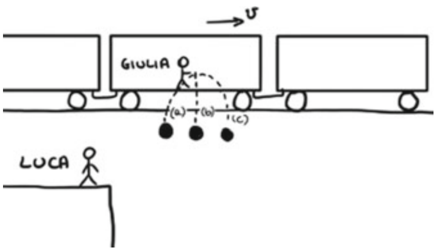

Fig. 5 Which is the path of the ball according to Luca (question 3) and Giulia (question 4)

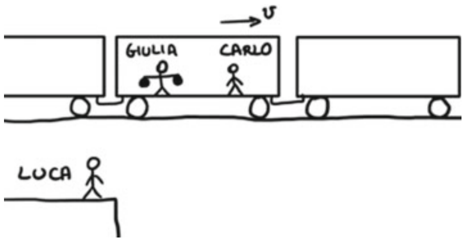

Fig. 6 In what order do the balls hit the ground according to Luca (question 10) and Carlo (question 11)

(see Fig. 4) are equally distributed over and under the lower bound. Ding and Beichner [40] suggested that the reason may consist in having misunderstood the request or in an extreme high or low value of the difficulty. The dependence on the difficulty may be consistent with our analysis especially for questions 1, 3–4 and 10–11.

Finally, the mean value of the point biserial coefficient (Table 2) is acceptable being over the lower bound threshold. Thus, each item is consistent with the other ones in the test. The test is internally coherent in investigating classical concepts. However, the Kuder-Richardson reliability index (Table 2) is out of range, suggesting that the test may not have a strong internal reliability. This means that the items of our test are not well connected [11]. The Ferguson's delta value is just above the threshold one. The test has an acceptable potentiality in discriminating among students at different levels even if the whole analysis suggests that our items should be reviewed, mainly trying to level out the difficulty.

4.2 Post-test

The post-test contains nine multiple-choice questions. The result of the analysis is shown in two tables: Table 3 displays the values of indexes P_i, D_i and r_{pbi} for all the items while Table 4 summarises the mean values for each index of Table 3 together with the value of the reliability index and the Ferguson's delta.

In Fig. 7 we plot the values of the difficulty index, the discrimination index and the point biserial coefficient index for each question with their lower bound.

The mean difficulty of the test is $\langle P \rangle = 0.66 \pm 0.05$ (Table 4): it is rather easy than difficult. Then to evaluate the discrimination index we again used students' score to the multiple-choice test as the internal criterion to gather them. We created four groups: the top quartile for students with score [8/9; 9/9], two middle groups for students with score [6/9; 7/9] and [4/9; 5/9] and finally the bottom quartile for students with score [2/9; 3/9]. The mean value of the discrimination index (Table 4) is $\langle D \rangle = 0.87 \pm 0.04$ well above over the desired value of 0.3, thus suggesting that the questionnaire is able to discriminate high-achieving students from low-achieving ones. From the comparison between difficulty and discrimination indexes we can conclude that questions 3–9 well discriminate top quartile students from low ones: the mean value of difficulty index for this subset is $\langle P_{[3\div9]} \rangle = 0.59 \pm 0.02$. This shows

Table 3 Value of the difficulty index, discrimination index and point biserial coefficient of the post-test. Sample size $N = 85$ students

Item	Difficulty index	Discrimination index	Point biserial coefficient
Question 1	0.9 ± 0.2	0.8 ± 0.1	0.3 ± 0.2
Question 2	0.9 ± 0.2	0.7 ± 0.1	0.2 ± 0.2
Question 4	0.5 ± 0.2	0.8 ± 0.1	0.4 ± 0.2
Question 6	0.6 ± 0.2	0.9 ± 0.1	0.5 ± 0.2
Question 8	0.5 ± 0.2	0.9 ± 0.1	0.5 ± 0.2
Question 10	0.7 ± 0.2	1.0 ± 0.1	0.6 ± 0.2
Question 11	0.6 ± 0.2	0.9 ± 0.1	0.6 ± 0.2
Question 12	0.5 ± 0.2	0.7 ± 0.1	0.4 ± 0.2
Question 13	0.6 ± 0.2	1.1 ± 0.1	0.7 ± 0.2

Table 4 Post-test statistics. Sample size $N = 85$ students. The desired values are taken from [40]

Test statistics	Post-test values	Desired values
Mean difficulty index	0.66 ± 0.05	[0.3, 0.9]
Mean discrimination index	0.90 ± 0.04	>0.3
Mean point biserial coefficient	0.47 ± 0.05	>0.2
Reliability index	0.59 ± 0.02	>0.7
Ferguson's delta	0.94	>0.9

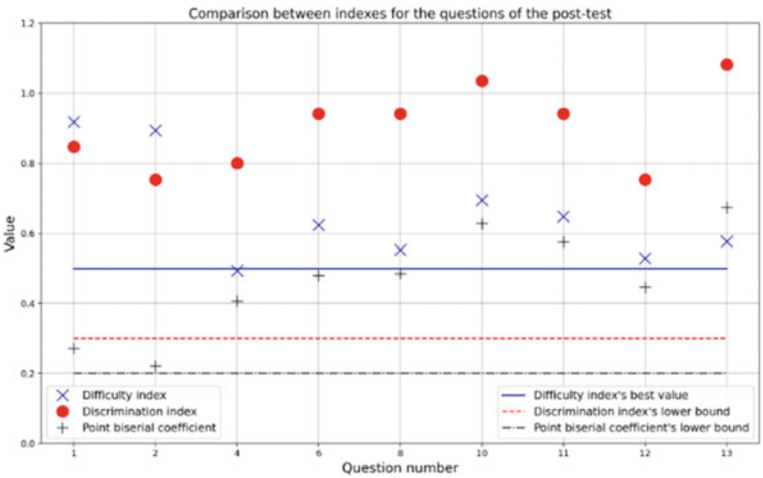

Fig. 7 Comparison between indexes difficulty (blue $\times$), discrimination (red $\circ$) and point biserial coefficient (black $+$) of the post-test. The corresponding lower bound is the blue solid line ($-$), the red dashed line ($--$) and the black dash-dot line ($-.$)

that questions 3–9 are neither too easy nor too difficult with respect to standard value of 0.5 (blue solid line): thus, the high value of D_i index with respect to threshold value (red dashed line) indicates a good discrimination. As for questions 1 and 2, we should have expected (see Fig. 7) a lower discrimination index due to their high difficulty index, showing a low difficulty. For these reasons, a revision of questions 1 and 2 may be considered.

The mean value of point biserial coefficient (Table 4) is $\langle r_{pbi} \rangle = 0.47 \pm 0.05$ above the desired value of 0.2: this means that each item is reliable in its request. However, as we can see from Fig. 7 the r_{pbi} value for question 1 and 2 is too close to the lower bound (black dash-dot line) with respect to the other items. It indicates that these two first questions do not test the material at the same level of the other ones.

Finally, we evaluate the entire test with Kuder-Richardson reliability index (r_{test}) and Ferguson's delta (δ). The first index (Table 4) has value $r_{test} = 0.59$ which is below the threshold of 0.7. We can infer that this is due to the fact that we selected a group of items from the Relativity Concept Inventory which only if considered as a whole is reliable (Aslanides and Savage [38]). Then our restricted subset may not be well connected. It is necessary to review items with too low discrimination index and point biserial coefficient. The value of the Ferguson's delta (Table 4) is greater than the lower bound, thus providing a good discrimination among students.

5 Conclusion

In this paper we described the pilot experimentation we carried out to investigate the possible effectiveness of introducing the spacetime globe in high-school teaching of Special Relativity.

We presented the results of the analysis of students' answers to the closed questions of two tests whilst the analysis of the open ones is remanded to a subsequent work currently under review. It arises a slightly greater difficulty in Classical Mechanics: considering only the closed questions, normalising for the total number of these items and of the students, the 64% of them well answered to items about Classical Mechanics while the 72% to the ones about Special Relativity.

The negative results arising from the analysis of the pre-test show that some concepts of Classical Mechanics are not accommodated at all (as the problems about trajectory in questions 3–4). More or less a quarter of the students ($\sim$23%) still believed in the existence of an absolute reference frame (question 8). It would be interesting to submit the questionnaire to high-school students that have just received instruction upon this topic to understand if the major problem consists in the high difficulty of the test or because students have forgotten some contents. This would be an important feedback in order to understand how to review our test. Indeed, its items were not taken from a validated one and this could be the reason for its non-consistency. Nevertheless, some items (as the first two) were taken from an exercise book of a high-school teacher, thus they should not be beyond their capabilities.

However, our results confirm the statement of Villani and Pacca [3] that it is not real to assume that students learning Special Relativity have already fully grasped the meaning of Galilean Relativity.

The items of the post-test were taken from the Relativity Concept Inventory [38] which was thought for higher instruction and needed revisions as the author wrote. As a whole, it emerges that the test is well structured. However, a revision, especially for question 1 and 2 and for items with too low discrimination index and point biserial coefficient may be considered to level out the global difficulty.

Other important considerations about the two tests will follow from the study of the open questions which will let us know more about students' beliefs, enriching and completing our analysis. In the next future we are going also to continue testing our proposal hopefully also in higher education, thus collecting more data to analyse. We then need to involve in our experimentation students possibly without misconceptions coming from the scholastic environment. Indeed, our sample of students had already attended scholastic lectures on Special Relativity. This may constitute a bias in the data analysis. Moreover, because of social distancing due to the CoronaVirus epidemic, students did not directly interact with the instrument.

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The Analysis of Conspiracy Theories as a Stimulus to Active Learning

Lucia Klinovská and Viera Haverlíková

Abstract The development of students' critical thinking, argumentation skills and formulating hypothesis is admittedly considered an integral part of physics education. The aim of our pedagogical experiment is to develop these skills by critical analysis of selected conspiracy theory related to physics phenomena. This paper describes the theoretical background and methodological notes to activity based on students' analysis of conspiracy theory related to 5G technology in the physics education at upper secondary school. Finally, the paper presents didactically processed experiences of implementation the activity into optional subject during distance education with 10 students.

Keywords Critical thinking · Argumentation · Hypothesizing

1 Introduction

It is generally known that we live in the information age. One of the direct impacts of the information age is the enormous amount of information that comes to us from various sources and which is related to different topics. Along with the true information, plenty of disinformation, rumours, hoaxes and conspiracy theories are spreading to us.

Conspiracy theories often relate to important spheres of social life. They are seemingly easy to understand and attractive. Although conspiracy theories are usually based on scientific rhetoric, they contain manipulative statements, they argue with

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concepts taken out of context and information that is not verified and substantiated by facts.

Nowadays, increasingly more people are confronted with conspiracy theories as a result of the widespread access to the internet [1]. Thus, it is crucial to assess every new piece of information critically. An individual who thinks critically analyses information and situations, evaluates evidence and arguments, and makes conclusions by using decision-making solutions [2]. Critical thinking is considered as important skill for life in 21 century [3]. Critical thinking is not an innate skill, it has to be learned, developed, practiced, and continually integrated into the curriculum [4–6]. The development of critical thinking related to argumentation skills and hypothesis formation stems not only from the need of the individual, but also from the requirements of society [7].

There is an expectation that education will lead students to form an opinion about conspiracy theories. Here, we utilized 5G technology conspiracy theory as a stimulus to active learning and development of above-mentioned skills in physics education on the age level 17–19 years. While choosing the specific conspiracy theory, its relation to physics content, curriculum, students' age, and relevance to current students' interest were considered.

2 Activity—Analysis of 5G Conspiracy Theory

We utilized 5G technology conspiracy theory as a stimulus to active learning. The aim of suggested activity is to offer students opportunity to develop their ability to analyze, evaluate and synthetize statements, to develop critical thinking, argumentation skills, hypothesis formation, forming and formulating evidence-based conclusions by critical analysis of a part of an article with conspiracy features. The development of above-mentioned skills is admittedly considered as an integral part of physics education [8, 9].

One of the conclusions of the research of Gavrilas et al. was that students have incomplete knowledge about the electromagnetic radiation emitted by mobile phones and wireless networks, while at the same time they have a negative attitude and consider it dangerous to the health of living organisms [10]. The Haverlíková points out the misconceptions about electromagnetic radiation among Slovak university students, students do not understand electromagnetic radiation, they do not consider visible light as a part of electromagnetic radiation, etc. [11]. The results underline necessity to discuss electromagnetic radiation of 5G mobile network and its interaction with matter with students.

The activity has fixing function in terms of factual knowledge. Its implementation requires students to have knowledge of electromagnetic spectrum, radiation, and energy. It is advisable to include suggested activity in the education within the physics course at the upper secondary school, secondary healthcare school and pre-service science teacher education. When including the suggested activity in the physics education, it is necessary to make sure that we carry out the activity in the group, in which students accept each other and they accept the classmates' different opinions.

2.1 The Activity's Preparation Process

The selection of the article with conspiracy content related to 5G technology was part of activity's preparation. Although, one of the competencies of critical thinking individual is the ability to select a reliable source of information [12], the article was chosen by us—teachers. The reason was to provide students with the same information resulting from the article and related to 5G technology. In selecting the article, we focused on an article that not only describes the dangers of 5G technology but is also based on physics concepts taken out of context related to electromagnetic radiation and its energy. We wanted to provoke students to form and formulate their opinion not only based on statements in the article but also on knowledge about electromagnetic radiation and energy.

After reviewing various websites, we selected an article The 5G War—Technology versus Humanity [13]. Due to the large length of the article, we selected only part of it—introduction, part describing Health Concerns Over 5G Abound and article's part answering the question What level of EMF Can Humans Withstand?

The selected part of the article warns of the danger of the 5G mobile network, i.e. exposure to electromagnetic field (EMF) and radiofrequency (RF) radiation. The article points out the electromagnetic radiation of 5G mobile network increase cancer risk, cellular stress increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficit neurological disorders and negative impacts on general well-being in humans.

5G electromagnetic radiation is non-ionizing radiation (tens of GHz) [14, 15] that is absorbed in the surface layers of the human body. Tissue heating is the main mechanism of interaction between radiofrequency fields of 5G mobile network and human body. 5G radiofrequency exposure levels result in negligible temperature rise in human body. As the frequency increases, there is less penetration into the body tissues and absorption of the energy becomes more confident to the surface of human body [16].

One of the strategies that support the development of critical thinking is EUR strategy. The EUR strategy involves three-phase educational model whose individual phases are Evocation, Comprehension and Reflection. In the phase of Evocation students actively remember knowledge related to the activity's topic, students compare their opinion with opinion of classmates, students formulate hypotheses and take an active interest in problem-solving. Phase of evocation provides possibility to physics teachers to motivate students and stimulate their interest in learning physics phenomena related to activity's topic. In the Comprehension phase students make themselves acquainted with new information (the most often through educational text). Students form and formulate their opinion about information from educational text and argue it based on knowledge related to the topic of text. In the phase of Reflection students identify and consolidate knowledge they gained through the process of learning. Students present how they changed their view of presented problem and identify shortcomings that should be changed before solving future problems [17, 18].

The structure of the activity Analysis of 5G conspiracy theory in distance form of the education is divided into two 90 min parts according to the EUR strategy with a spiral implementation of individual phases as specified in Table 1.

At the beginning of the activity's first part teacher acquaints students with the topic. Therefore, it is appropriate to start the activity by asking the question: "*Have you ever heard of the new generation of 5G technology?*" The teacher's role is not only to acquaints students with activity's topic, but also to ensure that the initial discussion does not focus on conspiracy theories related to physics phenomena related to 5G technology.

Then teacher sends the selected part of the article with conspiracy content related to 5G technology to students and acquaints them with their task. The students' task is to read the article individually and answer the question: "*If you could decide, would you approve the construction of a new 5G mobile network?*" It is important that the teacher assures students that they do not have to be afraid to express their own opinion and that their answers will not be evaluated, and teacher challenges them to answer through an audio recording. Then students read the assigned article individually and formulate their own opinions about 5G technology.

At the end of the first part students share their opinions by sending an audio recording to the teacher. We prefer the answer through the audio recording over the written form because we want to get spontaneous and initial students' opinions. We

Table 1 The structure of the activity in distance form of the education

<table>
<tr><td>I. Part</td><td>• Teacher acquaints students with activity's topic.
• Teacher sends the article with conspiracy content to the students and acquaints them with their task.
• Students individually read the assigned article and formulate their own opinion about 5G technology.
• Students share their opinion by sending an audio recording to the teacher.</td></tr>
<tr><td colspan="2">Teacher analyses students' answers and assess if they formed opinions based only on the statements in the article or also based on knowledge of electromagnetic radiation or other available information.</td></tr>
<tr><td>II. Part</td><td>• Students present their opinions in class.
• Teacher moderates a discussion aimed at physics phenomena related to 5G technology.
• Students formulate hypotheses resulting from the article and/or discussion and propose their verification.
• Students (with teacher's support) analyse the article from critical point of view.
• Students assess and compare their initial approach to article with critical analysis of the article.</td></tr>
</table>

also want to give students freedom, because sometimes it is easier to say our opinion than to formulate and write it.

Between the parts teacher analyses students' answers and assesses whether their opinions were formed only on the basis of the statements in the article or also on the basis of knowledge of electromagnetic radiation or other available information related to 5G technology. The analyse of recordings helps the teacher to prepare for the discussion, which is the main of activity' second phase and to avoid extreme situations, which could occur in group where students do not accept each other or do not accept different opinions.

At the beginning of activity' second phase students present their opinions in class. The teacher's role is to moderate a discussion aimed not at statements in the article but at physics phenomena related to 5G technology. During the discussion teacher can ask students following questions:

- *What do you know about radiation of 5G network?*
- *What type of radiation is the radiation of 5G network?*
- *What do you know about electromagnetic radiation?*
- *Do you know any type of electromagnetic radiation?*
- *What do you know about ionizing and non-ionizing electromagnetic radiation? Are they dangerous for humans?*
- *What causes non-ionizing electromagnetic radiation?*
- *How does non-ionizing radiation affect humans?*

Subsequently, the teacher focuses the students' attention on way of obtaining relevant evidence, which is verification of hypotheses. Students formulate hypotheses resulting from the article and/or discussion and propose their verification. At the end of the activity students (with the teacher's support) analyze the article from critical point of view and assess and compare their initial approaches to article's statements with critical analysis of it.

2.2 Implementation and Experience

The activity was carried out during the distance form of education with 10 students at upper secondary school on the age level 17–19 years according to the presented plan. At the beginning of the activity, we found out that 2 of 10 students hat not yet heard about 5G technology. It was a new concept for them. Therefore, we discussed the topic with them. During the discussion we found out that some students are familiar with conspiracy theories related to spreading coronavirus by 5G network. We briefly discussed the disinformation and pointed out the difference between correlation and causality.

Then, each of students read the article and formulated own opinion about 5G technology. At the end of the first part students shared their opinions by sending an audio recording to the teacher. Based on the critical analysis of students' opinions, we found out that five of them considered statements from the article to be true. Only two students critically analyzed and assessed statements in the article spontaneously.

At the beginning of the activity's second phase, we asked students who did not critically evaluated the article's statements to present their opinion related to 5G technology. Presentation of these opinions started a lively discussion. Students confronted and compared their opinions with each other. We asked students above-mentioned guiding questions related to electromagnetic radiation. Asked questions allowed students to think critically about article's statements. During the discussion, we also recorded physics knowledge on a shared whiteboard as shown in Fig. 1.

Through a conjoint discussion, the students found out that 5G electromagnetic radiation is a non-ionizing radiation that is absorbed in the surface layers of the human body.

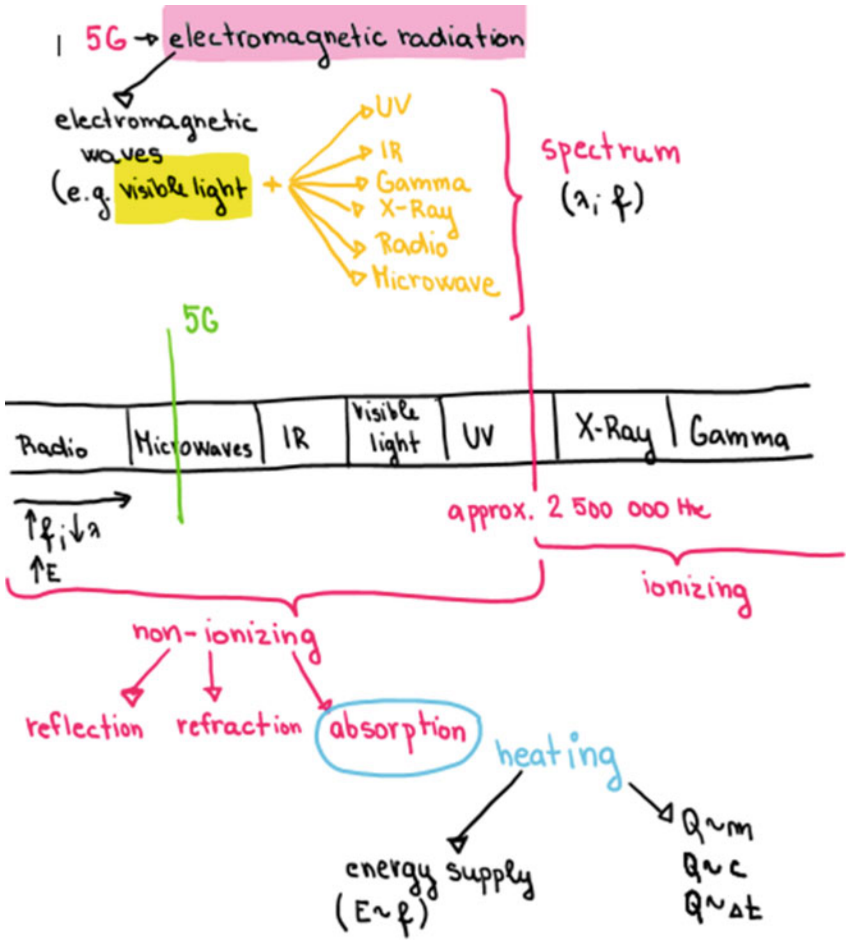

Fig. 1 Physics knowledge on a shared whiteboard

One of the ways to obtain relevant evidence is verification of hypotheses. We asked students questions: "What hypotheses follow from the article? Validity of what relationship between the variables could we verify?" Students formulated four hypotheses describing presumed interaction of electromagnetic radiation with matter:

- *Electromagnetic radiation of 5G mobile network increases cancer risk.*
- *Electromagnetic radiation of 5G mobile network increases in harmful free radicals.*
- *Electromagnetic radiation of 5G mobile network causes heating of the human body.*
- *As energy of electromagnetic radiation increases, the depth at which the temperature rises decreases.*

They proposed verification process of one of them—the last above mention hypothesis.

The most important part of the activity is the reflection. We asked students guiding questions aimed at comparison of their initial opinions related to 5G technology with opinion formulated after discussion. We challenged students to imagine that they would like to create conspiracy theory and spread it among people. We asked them to consider how to enhance the credibility of it so that as many people as possible would believe it. In response to described situation, students independently specified the features of conspiracy theories, which include for example an interpretation of the results that is not consistent with the actual results of the study, referring to the majority, and others.

At the end, students with our support critically analyzed the article and found the argumentation strategy and faults which increased the credibility of the article's statements.

3 The Evaluation of Students' Approaches to Form and Formulate Opinion About 5G Technology

The evaluation of the implementation and effect of the proposed activity was based on the characteristics of students. We assessed whether students participate in physics education actively or passively when teacher theoretically explains new concepts and when they carry out the experiment in previous physics education. We classified students as actively participated during theoretical explanation (AT) of new concepts by teacher, when they usually asked questions related to educational topic and answered teacher's question spontaneously. We classified students as passively participated during theoretical explanation (PT) of new concepts by teacher, when they did not answer teacher's question spontaneously, but only in case, when teacher challenged them to answer. We classified students as actively participated in carrying out the experiments (AE), when they individually formulated hypotheses or prediction related to the research question of the experiment, suggested and carried out the verification experiment and analyzed results of verification experiments in previous physics education. We classified students as passively participated in carrying out the experiments (PE), when they did not carry out above mentioned parts of experiment individually, but with instructional scaffolding of the teacher.

We analyzed students' initial opinion related to 5G technology and assessed whether they actively or passively participated in the second phase of the activity (discussion, reflection, critical analyses of the article). We classified students as actively participated in activity' second phase (A), when they spontaneously presented their initial opinion, answered above-mentioned guiding questions related to electromagnetic radiation and energy, formulated hypotheses to verify statements in the article, suggested verification experiment, analyses statement in the article from critical point of view during discussion and compared their initial approach to the statement in the article with critical analysis of it. If the students did not participate in second activity phase, but only in case, when teacher challenged them, we classified them as passively participated (P).

We present the evaluation of initial approaches to form opinion related to 5G technology manifested by 10 upper secondary school students in Table 2. The second column of the table shows active (A) or passive (P) participation of students in previous physics education during theoretical (T) explanation of new concepts by teacher and during experiments (E) carried out during the physics education (i.e. AT = student usually actively participates in physics education when the teacher theoretically explains new concepts).

The third column of the table shows Y (yes) if student considered statements in the article to be true, N (no) if student considered statements in the article to be false and? if student did not determine the veracity of the statement.

The fourth column shows N (no) if student did not present available information from other sources in his opinion about 5G technology and Y (yes) if student' opinion included them. The letter in round brackets identifies, whether the student listed her/his information sources or not.

The fifth column shows Y (yes) if student's opinion included physics concepts from the article, N (no) if concepts used in the article were not used in the opinion.

The sixth column shows Y (yes) if student's opinion included physics concepts, that were not used in the article, N (no) if the opinion did not include such concepts.

The seventh column shows whether student analyzed 5G technology from critical point of view in his/her opinion (O), which he/she formed and formulated in the first phase of the activity or in the discussion (D), which took place in the second phase of the activity.

The eight column shows active (A) or passive (P) participation of students in the second activity's phase (discussion, reflection, critical analyses of the article).

We color-coded some fields of Table 2 to highlight significant and interesting results from the implementation the activity Analysis of 5G conspiracy theory in the physics education.

In the first column, we colored 2 fields with red—students (4, 9) did not hear about 5G technology before carrying out the activity.

Table 2 The evaluation of students' approach to form and formulate opinion about 5G technology

Student	student participates actively / passively in education	student considered article to be true	student included information from other sources (with reference)	student included physics concepts from the article	student's opinion includes physics concepts not used in the article	students analyzed 5G technology with critical point of view	student participated actively / passively in activity's second phase
1	PT[1]; AE[2]	Y[3]	N[4]	N[5]	N[6]	D[7]	A[8]
2	AT[9]; AE	Y	N	Y[10]	N	D	A
3	PT; PE[11]	N[12]	Y (Y)[13]	Y	Y[14]	O + D[15]	A
4	AT ; PE	?[16]	Y (N)[17]	Y	Y	D	A
5	AT ; AE	Y	Y (N)	Y	N	D	A
6	PT ; PE	N	Y (N)	Y	Y	D	A
7	PT ; PE	?	Y (N)	N	N	D	A
8	PT; PE	N	Y (Y)	Y	Y	O + D	A
9	AT ; PE	Y	N	Y	N	D	A
10	AT ; PE	Y	N	Y	N	D	A

[1] PT—student is passive during theoretical explanation of new concepts by teacher
[2] AE—student actively participates in carrying out the experiments
[3] Y in third column—student considered statements in the article to be true
[4] N in fourth column—student did not included information from other available source related to 5G in the opinion
[5] N in fifth column—student did not include physics concepts from the article in the opinion
[6] N in sixth column—student did not include physics concepts that were not used in the article in the opinion
[7] D—student analyzed 5G technology from critical point of view only during the discussion
[8] A—student actively participates in the second activity's phase (discussion, reflection, critical analyses of the article
[9] AT—student is active during theoretical explanation of new concepts by teacher
[10] Y in fifth column—student included physics concepts from the article in the opinion
[11] PE—student passively participates in carrying out the experiments
[12] N in third column—student considered statements in the article to be false
[13] Y(Y)—student included information from other available source related to 5G in the opinion and listed the source
[14] Y in sixth column—student include physics concepts that were not used in article in the opinion
[15] O + D—student analyzed 5G technology from critical point of view in the opinion and also during the discussion
[16] ?—student did not determine the veracity of the statements in the article
[17] Y(N)—student included information from other available source related to 5G in the opinion but not listed the source

In the second column, we colored 4 fields with green—students (3, 6, 7, 8) passively participated when teacher theoretically explains new concepts and when they carry out the experiment in previous physics education.

In the fourth column, we colored 6 fields with yellow—students (3, 4, 5, 6, 7, 8) included information from other available source related to 5G in the initial opinion and two of them also listed the source of information.

In the seventh column, we colored 2 fields with blue—students (3, 8) analyzed 5G technology from critical point of view in the initial opinion and during the discussion.

Based on the critical analysis of students' opinions, we found out that five of them (1, 2, 5, 9, 10) including student 9, who did not hear about 5G technology before carrying out the activity considered statements from the article to be true. Student 2 stated in audio recording: "On the basis of the article, I would not recommend the construction of 5G mobile network in Slovakia, because amount of scientist and doctors disagree with construction of 5G mobile network, and they pointed out that electromagnetic radiation of 5G mobile network is dangerous to human body." Only three students, who passively participated in previous physics education (3, 6, 8) considered statements in the article to be false. Student 6 stated in audio recording: "From my point of view the article seem to be one-sided (it presents only one point of view). If I only read the article, I would probably not agree with construction 5G mobile network. But I also read other articles and watched the video about 5G mobile Network on the YouTube channel Juraj Vie. Based on the information from the articles and video I agree with construction 5G mobile network. Student 4 who did not hear about 5G technology before carrying out the activity did not determine the veracity of the statements in the article, what could be a result of lack of information about 5G mobile network.

Two students, who passively participated in previous physics education (3, 8), critically analyzed and assessed article's statements spontaneously in their opinion related to 5G technology. The same two students (3, 8) included available information from other sources in their opinion and they also provided sources of included information. Student 3 stated in audio recording: "Electromagnetic waves of 5G mobile network travel at speed of light. As the frequency of electromagnetic waves increases, its energy increases. Gamma ray and roentgen radiation are ionizing electromagnetic radiation, which have high energy in electromagnetic spectrum. Ionizing radiation causes unwanted skin or tissue damage. I found out that frequency of ionizing radiation is about 2 500 000 GH, which is an about 80 000 times more that frequency of 5G mobile network. The only effect of electromagnetic radiation of 5G mobile network is heating human body, which is negligible."

All students actively participated in in activity' second phase, they spontaneously presented their initial opinion, answered above-mentioned guiding questions related to electromagnetic radiation and energy, formulated hypotheses to verify statements in the article, suggested verification experiment, analyses statement in the article from critical point of view during discussion and compared their initial approach to the statement in the article with critical analysis of it. By implementation of the activity in physics education we broke the lesson' stereotype, what caused that all students, including "typically passive" students, actively participated in the activity.

4 Conclusion

The strikingly low threshold for accepting information from an article underlines the need to incorporate this type of activities into the education. The activity successfully fulfilled the aim to offer students opportunity develop their critical thinking, argumentation skills and hypothesis formation. Moreover, by breaking the lesson' stereotype, all students actively participated in the activity, they formed, formulated and presented their initial opinion about 5G technology, answered guiding questions, formulated hypotheses to verify statements in the article, suggested verification experiment, analyses statement in the article from critical point of view during discussion and compared their initial approach to the statement in the article with critical analysis of it. Students appreciated the opportunity to discuss about a conspiracy theory and express their opinion in a safe and supportive environment. We can conclude that this activity is suitable for implementation in the education.

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Correction to: The Analysis of Conspiracy Theories as a Stimulus to Active Learning

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In the original version of the book the author names was incorrectly published as "Klinovská Lucia and Haverlíková Viera" in chapter 13 which has now been corrected to "Lucia Klinovská and Viera Haverlíková". The correction to this book have been updated with the changes.

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