Challenges in Physics Education

Joan Borg Marks
Pauline Galea
Suzanne Gatt
David Sands *Editors*

Physics Teacher Education

What Matters?

Springer

Challenges in Physics Education

Series Editor

Marisa Michelini, Dipartimento di Fisica, University of Udine, Udine, Italy

This book series covers the many facets of physics teaching and learning at all educational levels and in all learning environments. The respective volumes address a wide range of topics, including (but not limited to) innovative approaches and pedagogical strategies for physics education; the development of effective methods to integrate multimedia into physics education or teaching/learning; innovative lab experiments; and the use of web-based interactive activities. Both research and experienced practice will feature prominently throughout.

The series is published in cooperation with GIREP, the International Research Group on Physics Teaching, and will include selected papers from internationally renowned experts, as well as monographs. Book proposals from other sources are entirely welcome.

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.

Book proposals for this series my be submitted to the Publishing Editor: Marina Forlizzi; email: Marina.Forlizzi@springer.com

Joan Borg Marks · Pauline Galea · Suzanne Gatt ·
David Sands
Editors

Physics Teacher Education

What Matters?

Springer

Editors
Joan Borg Marks
Department of Physics
University of Malta
Msida, Malta

Pauline Galea
Department of Geosciences
University of Malta
Msida, Malta

Suzanne Gatt
Department of Early Childhood
and Primary Education
Faculty of Education, University of Malta
Msida, Malta

David Sands
Freelance Education Consultant (Physical Sciences)
Cottingham (nr Hull), UK

ISSN 2662-8422 ISSN 2662-8430 (electronic)
Challenges in Physics Education
ISBN 978-3-031-06192-9 ISBN 978-3-031-06193-6 (eBook)
https://doi.org/10.1007/978-3-031-06193-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Papers from Keynote Contributions

Exploring Multimedia to Adapt Interactive Lecture Demonstrations (ILDs) for Home Use

David R. Sokoloff

Abstract With the need for distance learning materials thrust upon us alarmingly and suddenly by the Covid-19 pandemic, it is not unreasonable that many have fallen back on passive presentation of lectures and black/whiteboard notes using some mode of video conferencing. But is it possible to maintain some element of active learning for our introductory physics students? This paper will describe attempts to use the wealth of multimedia materials currently available (videos, simulations, photos, computer-based laboratory graphs, etc.) to adapt Interactive Lecture Demonstrations (ILDs*)* into a form that can be used by students at home. While recognizing that small-group discussions—and sharing in any way—may be difficult for many, these Home-Adapted ILDs retain student predictions as an essential element in engaging students in the learning process. This paper will review the design features of ILDs, describe some of the multimedia resources that are freely available, and present some examples of Home-Adapted ILDs. As we enter an uncertain future, this approach could have important applicability for pre-service and in-service teacher preparation programs, as well as for undergraduate physics students.

Keywords Active learning · Interactive lecture demonstrations · Distance learning · Virtual learning · Multimedia

1 Introduction

Interactive Lecture Demonstrations (ILDs) are an active learning strategy first developed in the 1990s and designed to promote the active engagement of students in learning physics concepts from live lecture demonstrations (Sokoloff and Thornton 1997, 2004; Sokoloff 2016). Students, including those planning to be teachers, come into their first introductory physics course at the high school or college level with definite views about physics concepts (often wrong) based on their life experiences that are not changed by traditional, passive instruction. Physics Education Research

D. R. Sokoloff (✉)
University of Oregon, Eugene, OR, USA
e-mail: sokoloff@uoregon.edu

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_1

(PER) has demonstrated that the vast majority of these students leave a traditionally taught course with the same (incorrect) views, and little understanding of physics concepts, regardless of the skill of the instructor (Hake 1998; McDermott 1991).

In summary: *if no effort is made to engage students in the learning process, they will not learn physics concepts!* During the pandemic, we are faced with many learning environments *that are worse than traditional!* Are there ways that can help us maintain active learning for our students through virtual learning? This paper describes a strategy adapted from ILDs that students can use online, at home—Home-Adapted Interactive Lecture Demonstrations.

2 In-Class Interactive Lecture Demonstrations (ILDs)

Active learning environments, like ILDs, have the following characteristics:

(1) The instructor's role is as a guide—not as the authority;
(2) Students construct knowledge from observations of the physical world as much as possible;
(3) A learning cycle of prediction/observation/comparison is used—challenging students' beliefs;
(4) Collaboration with peers is encouraged;
(5) Laboratory work is often used to learn basic concepts;
(6) PER-validated, active learning materials are used as components of the course.

Students generally enjoy watching traditional lecture demonstrations, so does that mean that they are engaged by and learn from them? Research has shown that unless a special effort is made to engage students (e.g., by asking them to make predictions about the outcome of the demonstration), the majority of students cannot even correctly describe the result of a demonstration they experience in lecture after class (Crouch et al. 2004).

In-class ILDs are designed to engage students in the learning process as they observe and think critically about lecture demonstrations. Sequences of *single*-concept demonstrations are presented using an eight-step procedure. The left side of Table 1 lists the steps.

ILDs are designed to introduce or review the most important concepts to be learned in the course. In a typical course, one lecture a week might be devoted to ILDs. Once students have mastered these concepts, other lectures can build upon this understanding. ILDs have also been used in conjunction with laboratories to introduce students to the concepts to be explored and to the apparatus that they will use, before beginning lab work.

Using the ILD procedure with carefully designed ILD sequences has been demonstrated to improve students' understanding of physics concepts (Sokoloff and Thornton 1997; Sokoloff 2016). Complete written materials (prediction and results sheets) for ILDs in 28 different topic areas from the introductory calculus-based or

Table 1 The steps of the In-Class and Home-Adapted ILD procedures

Steps of In-Class ILDs	Steps of Home-Adapted ILDs
1. Describe the demonstration and do it for the class without displaying the results	1. Student downloads the prediction sheet (a word document)
2. Ask students to record individual predictions on a prediction sheet. (Students are assured that predictions are not graded right or wrong, although a small amount of credit might be awarded for attendance on days that ILDs are carried out in lecture.)	2. Student reads written description of the demonstration and may view a photo, sketch, or video of the apparatus
3. Have the class engage in small-group discussions	3. Student records individual predictions on the prediction sheet
4. Elicit common student predictions from the whole class	4. *Only after recording predictions*, student views the demonstration as photo(s), video(s), or simulation(s) and observes the results
5. Ask students to record their final predictions on the prediction sheet (which will be collected at the end of lecture)	5. Student describes the results on the prediction sheet, compares them with predictions and often answers probing questions that guide critical thinking about the results. (The instructor may choose to have students send in the filled-out prediction sheet.)
6. Carry out the demonstration and display the results in an understandable way	This procedure is followed for each of the demonstrations in the sequence. There is no results sheet, but student may keep a record on a sheet of paper
7. Ask for a few student volunteers to describe the results and discuss them in the context of the demonstration	
8. If appropriate, ask for a few student volunteers to discuss analogous physical situations with different "surface" features, or describe an application of the illustrated concept	
This procedure is followed for each of the demonstrations in the sequence. Students may fill out a results sheet as a record to take home with them	

algebra-based physics course are available in the book, *Interactive Lecture Demonstrations*, published by Wiley (Sokoloff and Thornton 2004). The book also contains background information on the origins of ILDs, teachers' guides on each of the sequences, and teacher preparation notes to aid with presentations in class.

3 Home-Adapted Interactive Lecture Demonstrations (ILDs)

When in March 2020 it became apparent that we were experiencing a pandemic from Covid-19 that would severely limit students' in-class experiences around the world for an unknown period of time, the author began a project to adapt the available ILD sequences for use by students at home, online. This Home-Adapted ILD project [1] was based on the following design principles:

(1) The ILDs are largely based on in-class ones in the ILD book (Sokoloff and Thornton 2004);
(2) As with the in-class ILDs, they are designed to introduce concepts or review or clarify them;
(3) They are envisioned to be one of a number of at-home components of a course;
(4) Since many faculty users might have little experience with the features of online platforms like Zoom[2], the ILDs envision students working alone online, with no requirement of collaboration through group work (although individual faculty could choose to add such features);
(5) In place of live demonstrations, the Home-Adapted ILDs make use of available multimedia (photos, videos, graphs, and simulations, e.g., PhETs[3], Physlets[4], etc.) for students' experimental observations.

These considerations led to a modification of the eight-step in-class ILD procedure. The right side of Table 1 lists the revised five steps. Small-group discussions and sharing of ideas with the entire class are dropped, while predictions are retained to engage the students' attention and critical thinking.

Table 2 contains a list of the 26 sequences of Home-Adapted ILDs that have been developed. The remainder of this paper describes some examples from these, and how the available multimedia resources were incorporated in them in place of live demonstrations.

4 Image Formation with Lenses Home-Adapted ILDs

The "Image Formation with Lenses" Home-Adapted ILDs are based on the original in-class ILDs of the same name (Sokoloff and Thornton 2004; Sokoloff 2016). They deal with the real image formed by a converging lens, the representation of this process with a ray diagram, and the effect on the image of various changes in the experiment, for example blocking half of the lens, blocking half of the object, removing the lens, etc. Figure 1 shows a screenshot of the webpage for these ILDs.

---

[1] https://pages.uoregon.edu/sokoloff/HomeAdaptedILDs.html

[2] See, for example, https://zoom.us

[3] https://phet.colorado.edu/en/simulations

[4] https://www.compadre.org/Physlets

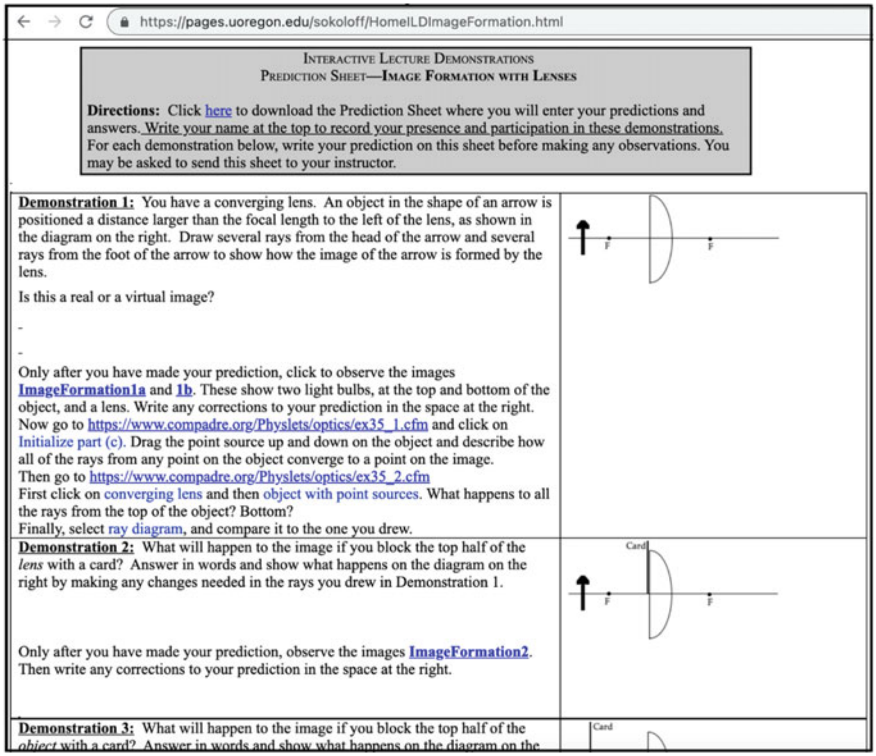
Table 2 The 26 Home-Adapted ILD sequences

1. Kinematics 1-Human Motion	14. Magnetic Forces
2. Kinematics 2-Changing Motion	15. Electromagnetic Induction and Faraday's and Lenz's laws
3. Force and Motion-Newton's 1st and 2nd Laws	16. Reflection and Refraction
4. Force and Motion-Newton's 3rd Law	17. Image Formation with Lenses
5. Vectors	18. Polarized light
6. Two-Dimensional Motion: Projectile Motion	19. Interference of light
7. Kinetic and Potential Energy	20. Diffraction of light
8. Momentum	21. Simple Harmonic Motion
9. Rotational Motion	22. Sound
10. Electrostatic Field, Force, and Potential	23. Introduction to Heat and Temperature
11. Introduction to DC circuits	24. Specific Heat
12. Current in series and parallel circuits	25. Phase Change
13. RC circuits	26. Heat Engine

Note that students first download the Prediction Sheet for these ILDs by clicking in the Directions box. They are then presented with a scenario of an object outside the focal point of a converging lens and asked to draw a ray diagram. After they have completed their diagram, they can click on two links to see photos of the experimental apparatus, consisting of two light bulbs (point sources) and an acrylic lens. Figure 2a and b show the photos viewable at these two links, first with the light bulbs off and then with them illuminated.

To complete demonstration 1, there are two links to parts of the Physlet "Lenses"[5], helping the students to visualize the infinite number of rays (cone of light) that emanate from each point on the object and to compare their ray diagram to a correctly drawn one. As can be seen in Fig. 1, demonstration 2 explores what will happen if the top half of the lens is blocked by a card. This demonstration in its in-class form (along with the ones that follow) has been demonstrated to help students understand the consequences of cones of light from a point source, rather than thinking of a small number of discrete rays (Sokoloff 2016).

[5] https://www.compadre.org/Physlets/optics/intro35.cfm



https://pages.uoregon.edu/sokoloff/HomeILDImageFormation.html

INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET—IMAGE FORMATION WITH LENSES

Directions: Click here to download the Prediction Sheet where you will enter your predictions and answers. Write your name at the top to record your presence and participation in these demonstrations. For each demonstration below, write your prediction on this sheet before making any observations. You may be asked to send this sheet to your instructor.

Demonstration 1: You have a converging lens. An object in the shape of an arrow is positioned a distance larger than the focal length to the left of the lens, as shown in the diagram on the right. Draw several rays from the head of the arrow and several rays from the foot of the arrow to show how the image of the arrow is formed by the lens.

Is this a real or a virtual image?

Only after you have made your prediction, click to observe the images **ImageFormation1a** and **1b**. These show two light bulbs, at the top and bottom of the object, and a lens. Write any corrections to your prediction in the space at the right.
Now go to https://www.compadre.org/Physlets/optics/ex35_1.cfm and click on Initialize part (c). Drag the point source up and down on the object and describe how all of the rays from any point on the object converge to a point on the image.
Then go to https://www.compadre.org/Physlets/optics/ex35_2.cfm
First click on converging lens and then object with point sources. What happens to all the rays from the top of the object? Bottom?
Finally, select ray diagram, and compare it to the one you drew.

Demonstration 2: What will happen to the image if you block the top half of the *lens* with a card? Answer in words and show what happens on the diagram on the right by making any changes needed in the rays you drew in Demonstration 1.

Only after you have made your prediction, observe the images **ImageFormation2**. Then write any corrections to your prediction in the space at the right.

Demonstration 3: What will happen to the image if you block the top half of the *object* with a card? Answer in words and show what happens on the diagram on the

Fig. 1 Screenshot of portion of the webpage for the "Image Formation with Lenses" Home-Adapted ILDs

5 Force and Motion-Newton's 3rd Law Home-Adapted ILDs

The "Force and Motion-Newton's 3rd Law" Home-Adapted ILDs are again based on the original in-class ILDs (Sokoloff and Thornton 2004). They deal with:

(1) identifying action-reaction pairs of forces and
(2) establishing, through a number of scenarios, exactly what Newton's 3rd Law means, namely that these pairs are always equal in magnitude and opposite in direction.

The experiments make use of two force sensors mounted on carts that interact with each other in various ways. Videos simultaneously display the motions of the carts and the force versus time graphs. IOLab smart carts [6] were used to create the videos, although any computer-based laboratory system and carts could be used[7].

[6] https://store.macmillanlearning.com/us/product/iOLab-Version-2.0/p/1464101469
[7] https://www.vernier.com; https://www.pasco.com

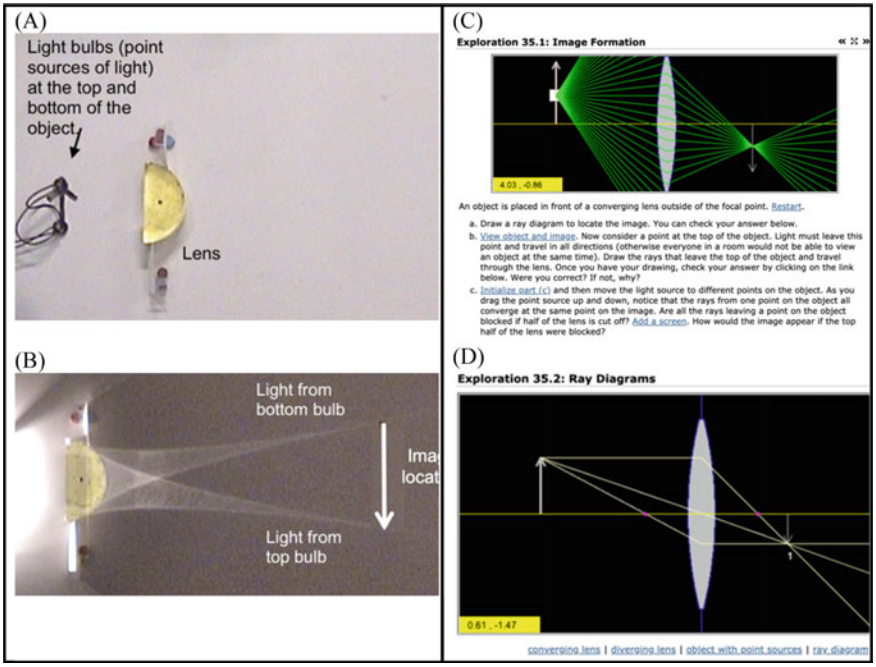


Fig. 2 Images from the Home-Adapted ILDs "Image Formation with Lenses" demonstration 1. **a** Experimental apparatus. **b** Formation of real image. **c** Simulation of multiple rays with movable point source on the object from the physlet "lenses." **d** Ray diagram from the physlet "lenses"

Figure 3a shows an excerpt from the downloadable Prediction Sheet. Students are first asked to make predictions for demonstrations 1–3 in which a heavier cart is pushed by another, first speeding up, then moving at a steady speed, and finally slowing down to a stop. Figure 3b shows the final frame of the video of this demonstration. It is clear from the force-time graphs that the two forces are equal and opposite during all three parts of the carts' motion. Demonstrations 4–8 involve different collisions between the two carts. In each case, students are asked to predict the forces before observing the video. Figure 3c shows a frame from the video for demonstration 6, an asymmetrical collision between heavy and light carts, with the heavy cart initially moving and the lighter one at rest. Having been engaged by the predictions, the observations convince the vast majority of students that action-reaction forces are always equal and opposite.

The in-class form of these ILDs has been demonstrated through pre and post-testing to significantly improve students' understanding of these concepts (Sokoloff and Thornton 1997).

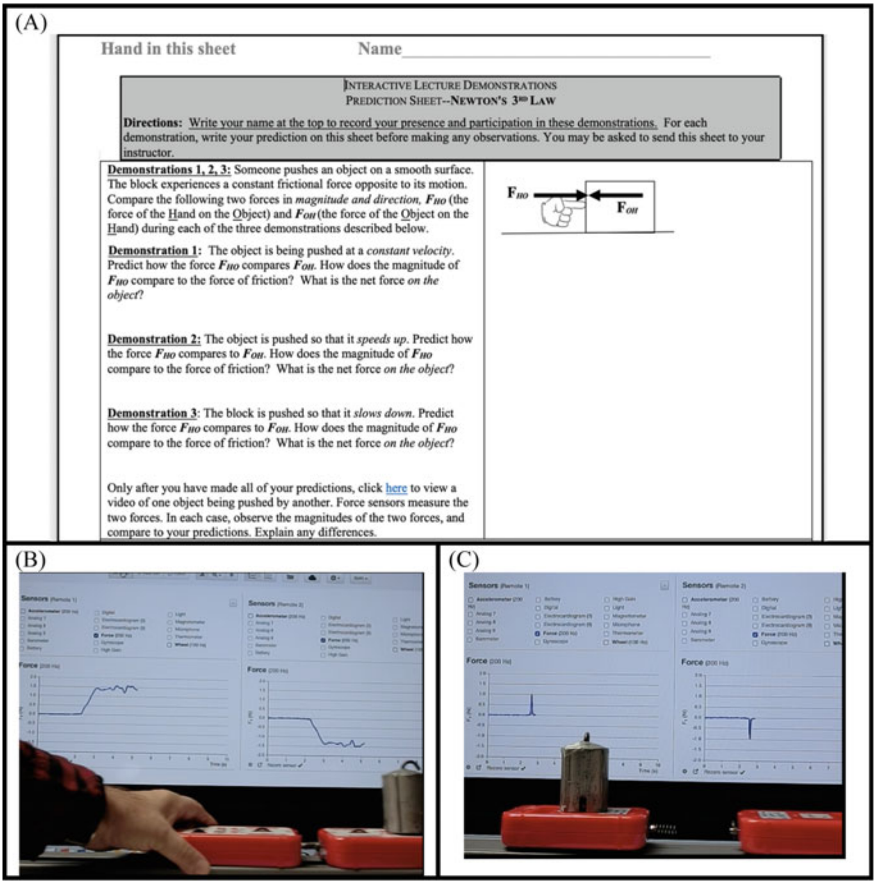


Fig. 3 **a** Excerpt from prediction sheet for the Home-Adapted ILD sequence “Force and Motion-Newton’s 3rd Law.“ **b** Force-time graphs of action-reaction pair of forces when a heavy IOLab is pushed along by a lighter one (demonstrations 1–3). **c** Force-time graphs for a heavier IOLab colliding with a lighter one (demonstration 6)

6 Introduction to DC Circuits Home-Adapted ILDs

Adapted from the original in-class ILDs of the same name, “Introduction to DC Circuits” introduces students to basic ideas about Ohm’s law, ohmic and non-ohmic devices, series and parallel connections, and the basic relationships between currents and voltages in these. Figure 4a shows an excerpt from the downloadable Prediction Sheet for these demonstrations.

To facilitate student observations at home with simple circuits, we make use of the PhET “Circuit Construction Kit”[8]. This simulation enables students to construct

[8] https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

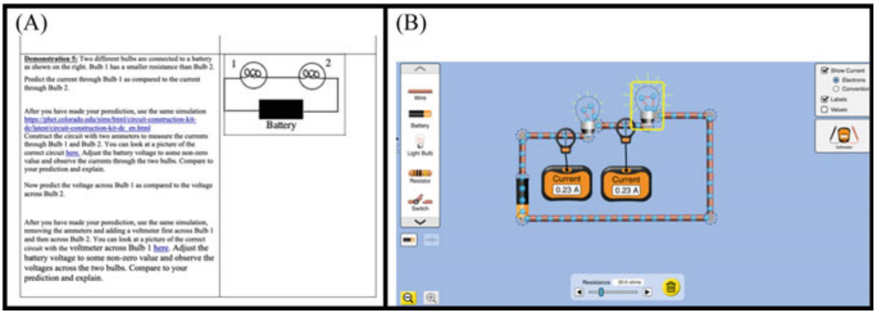


Fig. 4 **a** Excerpt from the prediction sheet used by students for the Home-Adapted ILDs "Introduction to DC Circuits." **b** Simple series DC circuit with two light bulbs of different resistances connected in series with a battery, set up in the PhET "Circuit Constriction Kit."

simple DC circuits of their choice by dragging circuit elements (bulbs, wires, batteries, switches, meters, etc.) into the workspace, and observing the resulting currents and voltages. Figure 4b shows a screenshot illustrating the observations for demonstration 5, comparing the currents flowing through two light bulbs of different resistances connected in series. Before an active intervention like this, the majority of students in an introductory course would predict that current is "used up" flowing through a light bulb, and therefore, the current flowing through the bulb on the right would be larger than that flowing through the one on the left.

7 Introduction to Heat and Temperature Home-Adapted ILDs

As a last example of Home-Adapted ILDs, Fig. 5a shows an excerpt from the downloadable Prediction Sheet for "Introduction to Heat and Temperature." This sequence of ILDs, like the original in-class ones, is designed to intervene with student confusion about the concepts of "heat" and "temperature". A number of demonstrations are set up to look at situations in which it is clear that temperature change and heat flow are related, but are decidedly not the same thing.

In demonstrations 1 and 2 (the latter illustrated in Fig. 5) a hot piece of metal cools to room temperature under two scenarios:

(1) coming to equilibrium in the air and
(2) coming to equilibrium in room-temperature water

In demonstration 2 the temperatures are measured by two Vernier [9] temperature sensors, one in the water and the other embedded in a small brass cylinder. The data are displayed with Vernier LoggerPro software, and the entire scenario—both

[9] https://www.vernier.com

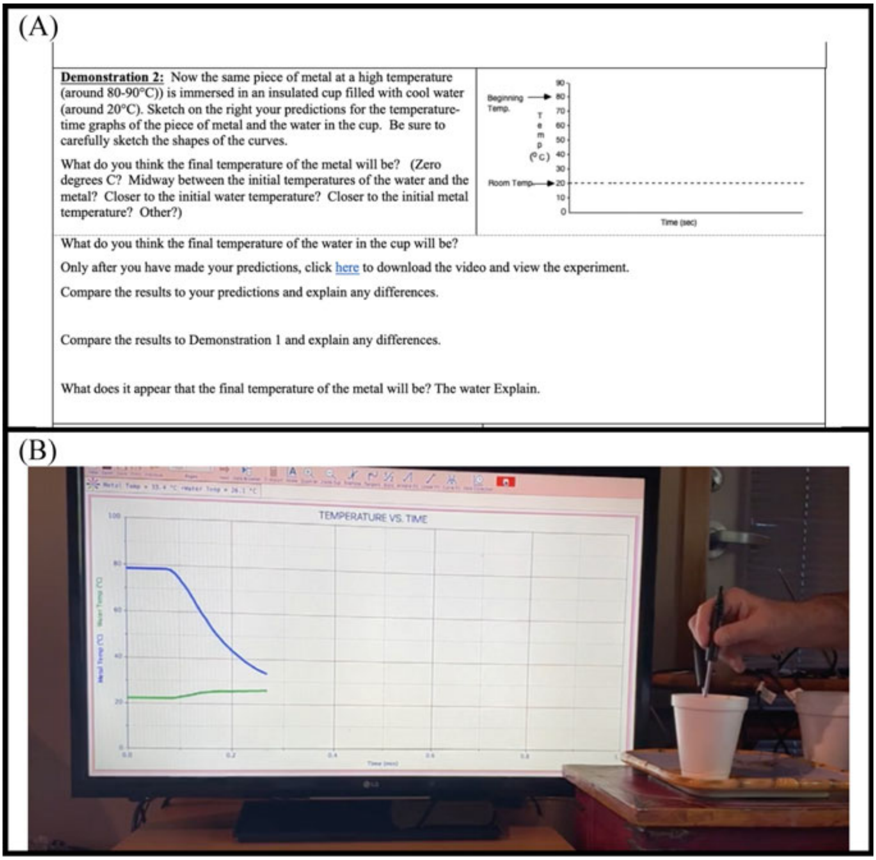


Fig. 5 **a** Excerpt from downloadable prediction sheet for Home-Adapted ILDs "Introduction to Heat and Temperature" showing demonstration 2. **b** Frame from a video showing the experiment and the evolution of graphs of the temperatures of a hot piece of brass (blue) immersed in cold water (green) as they come to thermal equilibrium

experiment and data display—is recorded on a video. Figure 5b shows a frame from this video. After comparing the observed results to their predictions, the students are asked to compare the results to the ones when the brass cools in air.

8 Conclusions

ILDs were first developed 30 years ago as one strategy to make a large (or small) lecture class a more active learning environment. Research evidence has demonstrated the effectiveness of this classroom strategy (Sokoloff and Thornton 1997; Sokoloff 2016). The availability of vast multimedia resources has enabled the author to develop Home-Adapted ILDs in which these resources substituted for live demonstrations allow students to carry out the prediction, observation, and comparison components of ILDs. Using these resources, Home-Adapted ILDs in most topic areas from the introductory physics course has been developed.

Because the Home-Adapted ILDs were developed under the duress caused by the Covid-19 pandemic beginning in March 2020, it has not been possible to organize research studies on their effectiveness. If they are to be used in the future, studies using pre- and post-testing should be carried out, similar to those carried out for in-class ILDs (Sokoloff and Thornton 1997; Sokoloff 2016). However, it is speculated that retention of the prediction, observation, and comparison steps should result in robust conceptual learning.

Acknowledgements The author thanks Marisa Michelini of the University of Udine and GIREP for recognizing his work with the GIREP Medal, and for providing numerous opportunities over more than a quarter-century for him to share his efforts with the international physics education community. He thanks Ronald Thornton of Tufts University and Priscilla Laws of Dickinson College for their contributions to the development of the in-class ILD strategy, and for over 30 years of collaboration on physics education research and curriculum development. The development of in-class ILDs and other active learning approaches was partially sponsored by the U.S. National Science Foundation and Department of Education. Finally, he thanks all the developers over the years of the magnificent collection of multimedia resources for supporting the teaching of physics that was available for use online when Covid-19 thrust us into this unexpected and unwanted adventure in physics education.

References

Crouch C, Fagen A, Callan JP, Mazur E (2004) Classroom demonstrations: learning tools or entertainment? Am J Phys 72:835

Hake R (1998) Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. Am J Phys 66:64

McDermott LC (1991) Millikan lecture 1990: what we teach and what is learned—closing the gap. Am J Phys 59:301

Sokoloff DR (2016) Active learning of introductory light and optics. Phys Teach 54(1):18–22

Sokoloff DR, Thornton RK (1997) Using interactive lecture demonstrations to create an active learning environment. Phys Teach 35(6):340

Sokoloff DR, Thornton RK (2004) Interactive lecture demonstrations. Wiley, Hoboken, NJ

QuILTs: Validated Teaching–Learning Sequences for Helping Students Learn Quantum Mechanics

Emily Marshman and Chandralekha Singh

Abstract We have been developing and validating teaching–learning sequences for use in quantum mechanics courses, called Quantum Interactive Learning Tutorials (QuILTs). Here we describe the development and validation of a guided inquiry-based QuILT focusing on a Mach–Zehnder interferometer with single photons that strives to help students develop the ability to apply fundamental quantum principles to physical situations in quantum optics. We describe how cognitive task analyses and empirical investigations of student difficulties informed the development of the QuILT and discuss specific examples of how the QuILT was iteratively refined. We present the findings from in-class evaluations suggesting that the QuILT was effective in helping students learn abstract quantum concepts in the context of a Mach–Zehnder interferometer experiment. Implications for developers of teaching–learning sequences and learning progressions researchers are discussed.

Keywords Physics education research · Quantum physics · Research-validated learning tools · QuILTs · Teaching-learning sequences · Single-photon experiments

1 Introduction

Many researchers have been focusing on developing teaching–learning sequences, which are well-validated learning activities that use research on student reasoning as a guide, based on empirical research (Meheut and Psillos 2004; Andersson and Bach 2004; Psillos and Kariotoglou 2015). For example, in physics, researchers have developed Interactive Learning Tutorials (McDermott and Shaffer 1992, 2002; McDermott 1996; McDermott et al. 1994) that are used frequently in the teaching and learning of physics concepts. Interactive learning tutorials are a type of Teaching–Learning Sequence (TLS) that aim to deepen students' conceptual understanding and reasoning skills. They are based upon a cognitive task analysis from an expert perspective (Wieman 2015; Reif 1995) and empirical research on student reasoning

E. Marshman · C. Singh (✉)
Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA
e-mail: clsingh@pitt.edu

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_2

and the common difficulties. Interactive learning tutorials use a guided inquiry-based approach and use student difficulties as resources to help them develop a robust understanding of physics.

TLSs are positioned within broader learning progressions, which are descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as students learn about and investigate a topic; they layout in words and examples what it means to move toward more expert understanding (Maries et al. 2017a; National Research Council. Learning Progressions 2007; Masters and Forster 1997; Alonzo and Steedle 2008). Development of effective TLSs involves knowledge of where students are in the learning progression—i.e., the prior knowledge students need to bring to bear in order to develop expertise in a topic. Developers of TLSs also need to identify "expert understanding" in the topic at hand. Identifying the knowledge and skills required for expertise in a particular topic involves performing a cognitive task analysis with experts in the field. However, content experts' cognitive processes are often implicit and automated (Singh 2002; Singh 2008a; Singh 2008b; Lin and Singh 2015, 2013, 2011) and experts may overlook steps, skills, or processes in the learning progression. As a result, it is imperative that educational researchers also refine TLSs via interviews with students to fill in any "gaps" that content experts may have overlooked. Other issues such as the use of technology and providing students with additional resources as appropriate (e.g., quantitative models to help them understand concepts) should also be considered.

Here, we focus on the development and validation of TLSs for use within a broader quantum mechanics learning progression. Quantum mechanics can be a challenging subject for many students since one does not generally observe quantum phenomena in everyday experience and the formalism is unintuitive. Several studies have focused on student understanding and difficulties in quantum mechanics, cognitive issues related to learning quantum mechanics, and instructional strategies to improve teaching and learning in quantum mechanics (Jolly et al. 1998; Johnston et al. 1998; Müller and Wiesner 2002; Singh 2001, 2008a, 2008b; Wittmann et al. 2002; Zollman et al. 2002; Domert et al. 2005; Singh et al. 2006; McKagan et al. 2008; Lin and Singh 2009a; Kohnle et al. 2010a, 2010b; Michelini and Zuccarini 2014; Singh and Marshman 2015a; Marshman and Singh 2015a; Emigh et al. 2015; Gire and Price 2015; Michelini et al. 2020). We have been investigating the difficulties students have in learning quantum mechanics and developing guided, inquiry-based Quantum Interactive Learning Tutorials (QuILTs) to help students in upper-level quantum mechanics courses learn about foundational topics in quantum mechanics (Singh 2005, 2006a, 2006b, 2007; Singh and Zhu 2009; Mason and Singh 2009, 2010; Zhu and Singh 2009, 2012a, 2012b, 2012c, 2012d, 2012e, 2012f, 2013; Lin and Singh 2009b; Zhu 2011; Singh and Marshman 2014a, 2014b, 1509, 2015b, 2016; Marshman 2014, 2015, 2016; DeVore and Singh 2015, 2020; Brown 2015; Marshman and Singh 2015b, 2016, 2017a, 2017b, 2017c, 2018, 2019; Maries et al. 2015; Sayer et al. 2015, 2016a, 2016b; Keebaugh et al. 2016, 2018a, 2018b, 2019a, 2019b, 2019c; Brown et al. 2016; Siddiqui and Singh 2017; Singh et al. 2018, 2021; Asfaw, et al. 2108). A QuILT is a type of TLS based upon a cognitive task analysis (Wieman 2015; Reif 1995) from an expert perspective and empirical research on student reasoning and difficulties with quantum mechanics concepts. Here, we discuss the development, validation, and evaluation of a QuILT to help students develop a solid grasp of single-photon interference involving Mach–Zehnder interferometer (MZI) experiments (Schneider and LaPuma 2001; Maries et al. 2017b, 2020; Sayer et al. 2017). The QuILT strives to help students learn fundamental quantum mechanics concepts in the context of a Mach–Zehnder interferometer experiment with single photons. The QuILT uses student difficulties found via research as resources and utilizes visualization tools to help students build physical intuition about counter-intuitive quantum optics phenomena with single photons and extend what they have learned by applying the same concepts in different contexts. This paper describes how systematic investigations of student difficulties and cognitive task analyses from an expert perspective were used as guides in developing and refining TLSs in quantum mechanics (QuILTs) that strive to help students build a coherent knowledge structure of underlying concepts.

2 Methodology for the Development and Validation of the QuILT

Below, we discuss the structure of the QuILT and the theoretical learning frameworks that informed the development of the QuILT. Then, we provide a general overview of how the QuILT was developed and validated and describe some specific examples to illustrate how the QuILT was iterated during the development and validation process including in-class implementation.

2.1 Structure of the QuILT

The QuILT on single-photon interference in the context of a Mach–Zehnder interferometer experiment can be administered to students in upper-division undergraduate and post-graduate quantum mechanics courses after students have learned about the relevant concepts. The QuILT includes a pretest, which can be administered to students after traditional, lecture-based instruction on the basics of the MZI with single photons (but before students work through the QuILT). It also includes a posttest to be given to students after they work on the QuILT. The questions on the pretest and posttest are in an open-ended format so that students generate answers demonstrating understanding of the concepts.

The QuILT begins with a warm-up that helps students bring to bear their prior knowledge about reflection and transmission of waves and reason about the interference of a classical beam of light. The main section of the QuILT focuses on the fundamentals of quantum mechanics in the context of single-photon interference. Throughout the QuILT, students make predictions about a particular experimental setup, check their predictions via a computer simulation, and then reconcile the differences between their predictions and observations. Additional scaffolding support is provided throughout the QuILT to help students reconcile differences between their predictions and observations. The final part of the QuILT strives to help students integrate concepts of single-photon interference with quantitative reasoning. The scaffolding support in the QuILT is gradually reduced to help students reason about single-photon interference independently. The QuILT is best used in class to give students an opportunity to work together in small groups and discuss their thoughts with peers, which provides peer learning support. During group discussions, students can formulate and articulate their thoughts to solidify concepts and benefit from one another's strengths. Moreover, students monitor their own learning through discussions that can help them extend their knowledge and rectify their knowledge gaps. Students can be asked to work on the parts of the QuILT they could not finish in class at home as homework.

2.2 Frameworks Informing the Development of the QuILT

Empirical evidence suggests that the diversity in students' prior preparation, as well as the "paradigm shift" from classical mechanics to quantum mechanics, can result in learning difficulties (Marshman and Singh 2015a). Given that quantum optics experiments involving single-photon interference elucidate foundational issues in quantum mechanics, learning tools that focus on this experiment can help students make connections between the abstract quantum mechanics concepts and concrete experiments and learn the concepts better. The development of the QuILT on quantum optics experiments with single photons was inspired by several cognitive theories, all pointing to the importance of knowing student difficulties to help them develop a functional understanding of relevant concepts. The cognitive theories suggest that learning tools should use students' current knowledge as well as their difficulties as resources and build on them to help students develop a coherent knowledge structure.

For example, Hammer's "resource" model (Hammer 1994) suggests that students' prior knowledge, including their learning difficulties, should be used as resources to help students learn better. Similarly, the Piagetian model of learning emphasizes an "optimal mismatch" between what a student knows and is able to do and the instructional design with well-defined goals (Piaget 1978; Posner et al. 1982). In particular, this model focuses on the importance of knowing students' difficulties and using this knowledge to design instruction to help students assimilate and accommodate new ideas and build a good knowledge structure. Similarly, the framework of Schwartz, Bransford, and Sears (Schwartz et al. 2005), "preparation for future learning" (PFL), suggests that instructional design should include elements of both innovation and efficiency to help students become "adaptive experts" (i.e., experts who can efficiently solve routine problems and transfer their learning to solve novel problems) and transfer their learning from one context to another. While there are multiple interpretations of the PFL model, efficiency and innovation can be considered to be two orthogonal dimensions in instructional design. If instruction only focuses on efficiently transferring information, cognitive engagement will be diminished and learning will not be effective. On the other hand, if the instruction is solely focused on innovation, students will struggle to connect what they are learning with their prior knowledge and deep learning and transfer will be inhibited. Well-designed instruction balances elements of efficiency and innovation such that students remain in an "optimal adaptability corridor", i.e., a trajectory for the development of adaptive expertise in a particular domain. Vygotsky's (Vygotsky 1978) notion of the "zone of proximal development" (ZPD) is another synergistic model of student learning. The ZPD refers to the zone defined by the difference between what a student can do on his/her own and what a student can do with the help of an instructor who is familiar with his/her prior knowledge and skills. Scaffolding is at the heart of the ZPD model and can be used to stretch students' learning beyond their current knowledge using carefully crafted learning tools that provide scaffolding support. These frameworks are synergistic in that one can provide an optimal mismatch by ensuring that instruction is in the zone of proximal development and by designing instructional tasks that are in the "optimal adaptability corridor."

All these frameworks point to the fact that one must determine the initial knowledge states of students via research to design effective instructional tools commensurate with students' current knowledge and skills. The research on student conceptual difficulties involving the MZI with single photons and the development of the QuILT were based upon these synergistic models of student learning, which involve building on students' prior knowledge (including their conceptual difficulties) to help them develop a coherent knowledge structure of relevant concepts.

2.3 Development and Validation of the QuILT

The development and validation of the QuILT involve both a "top down" and "bottom up" approach to learning. The "top down" approach involves a cognitive task analysis of the underlying concepts from an expert perspective (Wieman 2015; Reif 1995). The "bottom up" approach to the development of the QuILT involves investigating students' prior knowledge and difficulties with single-photon interference found in written surveys and individual interviews after traditional instruction in relevant concepts. The development and validation of the QuILT went through a cyclic, iterative process which included the following stages:

- Development of the preliminary version based on a cognitive task analysis of the underlying knowledge and research on student difficulties with relevant concepts
- Implementation and evaluation of the QuILT by administering it individually to students and obtaining feedback from faculty members who are experts in these topics
- Determining its impact on student learning and assessing what difficulties were not adequately addressed by the QuILT

- Refinements and modifications based on the feedback from the implementation and evaluation.

The cognitive task analysis from an expert perspective involves a careful analysis of the underlying concepts in the order in which those concepts should be invoked and applied in each situation to accomplish a task. A cognitive task analysis often involves determining the objectives of the task and the requisite content knowledge and skills invoked to accomplish the task (and the order in which different concepts should be used). This analysis is useful in determining various milestones when learning quantum mechanics concepts and helps in determining the goals of the QuILT. In the development of our QuILT on single-photon interference, we as researchers are experts in quantum mechanics concepts and we performed an initial cognitive task analysis of how an expert would reason about single-photon interference. Then we discussed the expert cognitive task analysis with several other physics faculty members and refined the cognitive task analysis based upon their suggestions and feedback. The iterative cognitive task analysis from an expert perspective was useful for determining the goals for the QuILT, i.e., to use quantum optics experiments to reason about: (1) Interference of a single photon with itself (a photon has a nonzero probability of being found in two (or more) locations simultaneously and measurement will collapse the state of the photon); (2) How removing or adding optical elements (beam-splitters, detectors, and polarizers) can cause the photon to exhibit properties of either a wave or a particle and can destroy or recover the interference of a single photon. The cognitive task analysis allowed us to incorporate elements of efficiency into the QuILT, e.g., to appropriately sequence the questions in the QuILT to provide guidance and build on students' knowledge and skills (instead of expecting them to engage in discovery learning).

We also investigated student difficulties with single-photon interference to inform the development of the QuILT. The difficulties were investigated by administering multiple-choice and open-ended questions to upper-level undergraduate and post-graduate students in quantum mechanics courses after traditional instruction in relevant concepts. We observed difficulties on these questions which were administered on in-class quizzes and examinations. The undergraduate students were enrolled in an upper-division junior/senior-level undergraduate quantum mechanics course and the post-graduate students were enrolled in a first-year core quantum mechanics course. Student difficulties were also investigated by conducting individual interviews with 23 upper-level undergraduate and post-graduate student volunteers enrolled in the quantum mechanics courses (not necessarily the same students who answered the written questions). The individual interviews employed a think-aloud protocol (Chi 1994) to better understand the rationale for students' written responses. During the semi-structured interviews, we asked students to "think aloud" while answering the questions. Students first read the questions on their own and answered them without interruptions except that they were prompted to think aloud if they were quiet for a long time. After students had finished answering a question to the best of their ability, we asked them to further clarify issues that they had not clearly addressed earlier while thinking aloud. The investigation of student difficulties helped with the cognitive task analysis from students' perspectives. These investigations were useful to incorporate elements of efficiency and innovation in the QuILT. For example, we incorporated common student difficulties into various questions in the QuILT and provided scaffolding in order to guide and support student learning. In addition, knowledge of student difficulties allowed us to develop questions that provided the right amount of innovation, i.e., provided the appropriate level of challenge in order to keep the students actively engaged while working through the QuILT.

2.4 Refining the QuILT Based upon Cognitive Task Analyses and Knowledge of Student Difficulties

The research involving the cognitive task analysis and student difficulties, as well as the theoretical frameworks discussed earlier, were used as guides in the development of an initial version of the QuILT. The research-based QuILT actively engages students in the learning process using a guided inquiry-based approach in which various concepts build on each other. As noted, the initial version of the QuILT went through several refinements based upon interviews with students, discussions with physics faculty members, and additional written responses collected from students. Below, we describe the rationale for several refinements in the TLS during the initial development of the QuILT in which students engaged with it in a one-on-one interview situation and also after an initial in-class implementation.

2.4.1 Using Students' Prior Knowledge About Interference of a Classical Beam of Light as a Resource

During the development of initial versions of the QuILT, we found that students often had difficulty reasoning about the interference of a classical beam of light in written responses and interviews. For example, in the Mach–Zehnder interferometer experiment in Fig. 1, students often incorrectly claimed that if the intensity of light emitted from the source is I, the intensity at the two photo-detectors $D1$ and $D2$

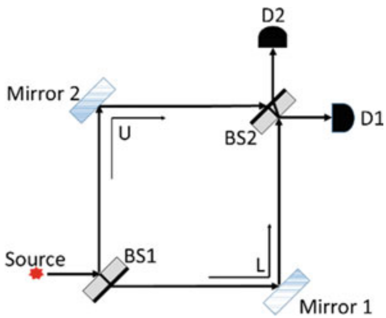


Fig. 1 Mach–Zehnder interferometer with beam-splitter 1 (BS1), beam-splitter 2 (BS2), the upper path (U), the lower path (L), detector 1 ($D1$), and detector 2 ($D2$)

would be *I/2*. Students justified this type of answer by reasoning that the experimental setup in Fig. 1 looks very symmetric and thus, half of the light arrives at each of the detectors. However, due to the phase shifts of the light throughout the interferometer, the light arrives in phase at detector $D1$ and displays constructive interference, i.e., all of the light arrives at detector $D1$ and the intensity of light at detector $D1$ is I. Destructive interference occurs at detector $D2$ because the light wave is out of phase at detector $D2$ and no light is observed there.

Students should have learned about the interference of a classical beam of light in their introductory physics courses, but they may not have brought that knowledge to bear when reasoning about a classical beam of light propagating through the Mach–Zehnder interferometer. The concepts of phase differences, constructive interference, and destructive interference for a classical beam of light are also critical in understanding single-photon interference, a quantum phenomenon. Thus, we developed a QuILT warm-up that precedes the main part of the QuILT to help students review the basics of interference of a classical beam of light before learning about single-photon interference in a Mach–Zehnder interferometer. The warm-up helps students to determine the phase shifts of a light wave propagating through the MZI and the type of interference (e.g., constructive or destructive) observed at each detector in Fig. 1. To help students reason about the phase shifts of a light wave when it propagates through the MZI, they are guided to make an analogy with a wave pulse on a rope since a wave pulse on a rope is easier to visualize and make sense of than light waves. Students use this concrete example that they have learned about in introductory physics to visualize the phase shift associated with reflection or transmission of a wave pulse based upon the physical properties of the rope. They then use the rope analogy to build intuition about the more abstract case of light waves and the phase shifts associated with the reflection, transmission, and propagation of light through different optical media.

2.4.2 Providing More Scaffolding to Students for Challenging Experimental Setups

In the QuILT, students work through different types of Mach–Zehnder interferometer experiments with different numbers of optical elements (e.g., polarizers) placed in the interferometer. In the cognitive task analysis from the expert perspective, it appeared that the most effective way to introduce polarizers into the MZI setup was to have students work through the "simpler" setups first (i.e., one polarizer in one of the paths of the MZI) and then build up to more complex MZI setups (i.e., two or three polarizers placed in the paths of the MZI). For example, students first worked through the MZI experiment in which one polarizer is placed in the interferometer. In this situation, some of the photons display interference whereas others do not. Then, students work through examples of single-photon interference in which there are two orthogonal polarizers, one in each path of the MZI. For example, one of the MZI setups involved a horizontal polarizer in the upper path (U) and a vertical polarizer in the lower path (L) between beam-splitters BS1 and BS2. In this situation, since the photon path states in the U and L paths are orthogonally polarized, there is no possibility for interference to occur and the detectors click with equal probability. Then, students work through the case in which there are three polarizers placed on paths of the MZI. In this case, depending on the orientations of the polarizers, interference can be observed at the detectors. In each situation, students have to reason about the percentage of photons arriving at each detector and whether or not interference is observed at the detectors $D1$ and $D2$.

However, we discovered from students' interviews and written responses that they found it very difficult to reason about the MZI setup with one polarizer. Although most students mentioned that some photons would be absorbed by one polarizer, they did not know how this setup would be different from the MZI setups with two or three polarizers. In the MZI setup with one polarizer, students have to reason about the fact that only a fraction of the photons show interference, and the rest of the photons do not display interference. This task was too innovative for many students and they had great difficulty qualitatively reasoning about the percentages of the photons that display interference and why photons of a certain polarization would interfere and others would not. In this case, we as content experts had an "expert blind spot" in the sense that we thought that a simpler MZI setup with only one polarizer would be easier for students to reason about than a complex MZI setup with two or three polarizers. However, this was not the case for students, and thus, we incorporated more scaffolding for the MZI setup with one polarizer. We also added quantitative questions as scaffolds to help students learn to determine the percentages of photons arriving at each detector and verify that photons of a particular polarization would interfere (whereas others would not) in the MZI setup with one polarizer.

2.4.3 Defining Unclear Terminology

"Which-path" information (WPI) is a common term associated with Mach–Zehnder interferometer experiments and was popularized by Wheeler (1978). WPI is "unknown" about a photon (as in the setup shown in Fig. 1) if both components of the photon state are projected into the detectors $D1$ and $D2$ and the projection of both components at each detector lead to interference. WPI is "known" about a photon if only one component of the photon path state can be projected into each detector. For example, if beam-splitter 2 (BS2) is removed from the setup in Fig. 1, WPI is known for all single photons arriving at the detectors $D1$ and $D2$, and each detector ($D1$ and $D2$) has an equal probability of clicking. The concept of "which-path" information (WPI) can be a useful tool for reasoning about whether interference will be observed at detectors $D1$ and $D2$. In particular, if WPI is known for the single photons arriving at the detectors $D1$ and $D2$, interference will not be observed at the detectors. If WPI is unknown, interference will be observed at both detectors.

However, we found that students had difficulty making sense of the term "which-path" information in their written responses and interviews. In particular, some students interpreted having "which-path" information about a photon as meaning that the photon must travel along one path in the interferometer. However, this type of reasoning is incorrect. The photon did not take only one path in the interferometer throughout, but rather, it is delocalized after it passes through beam-splitter BS1. The photon is in a superposition state of the U and L path states after passing through BS1, regardless of whether WPI is known at the detectors $D1$ and $D2$ depending upon the details of the setup.

Based upon this difficulty, we explicitly defined the term "which-path" information and incorporated more scaffolding within the QuILT to help students develop a better understanding of "which-path" information. Several questions about different Mach–Zehnder interferometer setups and experiments ask students about whether or not "which-path" information is known in those situations and how this concept is related to single-photon interference.

2.4.4 Re-Organizing the QuILT to Incorporate a Computer Simulation Effectively

Throughout the initial version of the QuILT, we included a computer simulation in which students can make predictions about different MZI experimental setups and check their predictions via the computer simulation (see Fig. 2). In the simulation, a single photon is portrayed as having a transverse Gaussian width and screens are used to display the interference pattern. Students were guided to think about how the transverse Gaussian profile of the photon may yield constructive or destructive interference at different points on the screen, creating an interference pattern on the screen (in situations in which interference should be observed).

However, after several discussions with faculty members and students, we realized that it was easier to reason about concepts related to single-photon interference using a simplified model in which the source emits a highly collimated stream of photons (i.e., photons are emitted as a single ray having an infinitesimally small width). Point detectors are used in place of screens. Therefore, we refined the QuILT such

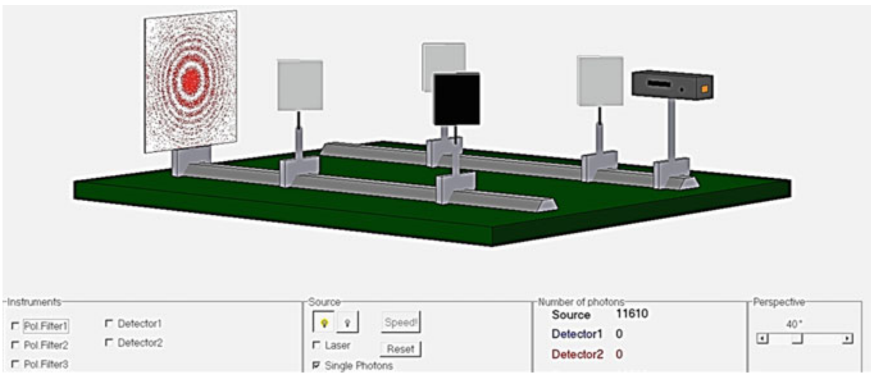


Fig. 2 Screenshot of the computer simulation of a large number of single photons propagating through the MZI. Simulation developed by Albert Huber

that students used this simplified model first to learn about the superposition (i.e., delocalization) of a photon in the two paths of the MZI, the collapse of the photon state when a photon is detected and interference phenomena in the QuILT. Students also learn how to qualitatively reason about the probability of a detector "clicking" (or registering a photon).

After working through the simplified model of a photon, students are then guided to think about the photon as having a transverse Gaussian width. Students learn that after passing through the interferometer, interference of the two paths of the photon state will lead to constructive and destructive interference at different points on the screen, depending upon the path length difference at those points on the screen. Students compare and contrast the two models of a photon, i.e., the photon emitted as a single ray having an infinitesimally small width, versus the photon having a transverse Gaussian width. Students can then use the computer simulation to verify that a single photon can exhibit wave properties while propagating through the MZI setup and interference fringes are observed on the screen (see Fig. 2). They are given opportunities to reconcile possible differences between their prediction and observation and learn that a photon in the MZI experiment can behave as a wave and display interference at detectors $D1$ and $D2$.

2.4.5 Refining the QuILT Based upon Student Responses to QuILT Sequences and Posttest Questions

After an initial in-class implementation of the QuILT, several students had difficulties with concepts from the QuILT on the posttest. Some difficulties were related, for example, to the fact that students were focused on the symmetry of the MZI setup in Fig. 1 and held a deep alternative conception that 50% of the photons arrive at detector $D1$ and 50% of the photons arrive at the detector $D2$. For example, on the posttest, some students claimed that the beam-splitter BS1 splits the photon into two photons. These students usually justified this claim by stating that the photon has an equal probability of being in the U and L paths and thus, the detectors $D1$ and $D2$ would click with equal probability. These students struggled with the fact that a single photon can behave as a wave passing through the MZI and be in a superposition of the U and L path states. They did not appropriately account for the fact that the two components of the photon path state can interfere at the detectors $D1$ and $D2$. Other students knew that the photon would be in a superposition of the two path states in the MZI, but interpreted this to mean that the photon is split into two photons. These students then claimed that these two photons interfere at the detectors (instead of the fact that the interference is due to the wave nature of single photons). One student with this type of view stated: "it seems like [each photon with half of the energy of the incoming photon traveling along the U and L paths of the MZI is] the only way for a photon to interfere with itself and have some probability of going through either path until getting measured". Some of these students claimed that $D1$ would register a photon 50% of the time and $D2$ would never register a photon because, although the photon arrives there 50% of the time, destructive interference "kills it".

These students did not appropriately account for the conservation law—that is, if N photons are emitted from the source, all N photons must be detected at the detectors $D1$ and $D2$ (if there is no absorption of photons in the paths of the MZI).

Thus, even though the QuILT had been implemented in one class, we continued to iterate the TLS in the QuILT to account for these types of difficulties. Throughout the QuILT, we incorporated several questions in the form of hypothetical student conversations that focus on these issues and students must state why they agree or disagree with the hypothetical students. In addition, the quantitative component of the QuILT strives to help students realize that the number of photons emitted from the source must be equal to the number of photons registered at the detectors (in the cases in which there is no absorption of photons). We found that in subsequent in-class implementations of the QuILT, fewer students displayed difficulties involving splitting of a single photon into two photons after passing through the MZI.

2.4.6 Developing an Additional QuILT Component that Integrates Quantitative and Qualitative Reasoning

The initial version of the QuILT focused on developing a conceptual understanding of single-photon interference in the context of Mach–Zehnder interferometer experiments. Students are asked to qualitatively reason about the percentages of photons arriving at the detectors $D1$ and $D2$ and determine whether interference is observed in different MZI experimental setups.

While we found after the initial in-class implementation that students' performance on the QuILT posttests was significantly improved after working through the QuILT that focused on the concepts compared to the pretests, students often mentioned in class and in interviews that they also wanted to learn how to reason about the concepts quantitatively. In addition, during discussions with researchers and content experts, we often used quantitative reasoning to think about whether interference is displayed in different MZI setups. Thus, it was determined that integrating conceptual understanding and quantitative reasoning was a valuable activity and we developed another component of the QuILT that strives to help students integrate conceptual aspects of the MZI involving single-photon inference with mathematical formalism. This component of the QuILT aims to help students develop a quantitative understanding of how beam-splitters and polarizers affect interference and measurement outcomes. Several students noted in individual interviews and after the second in-class implementation (which included the quantitative component of the QuILT) that they greatly appreciated the opportunity to integrate their conceptual understanding with quantitative reasoning.

3 Results from In-Class Implementations

The QuILT was administered to upper-level undergraduate and post-graduate students. Undergraduate students ($N = 44$) in two upper-level undergraduate quantum mechanics courses first had received instruction in relevant topics. The instruction included an overview of the quantum optics experimental setup and students learned about the basics of single-photon interference. Then students took a pretest (all students had sufficient time to work through the pretest). The QuILT warm-up was given to undergraduate students to work on at home. Students worked through part of the main QuILT in class and were given one week to work through the rest of the QuILT as homework. The pretest and QuILT counted as a small portion of their homework grade for the course. The undergraduate students were then given a posttest in class after they turned in the QuILT (all students had sufficient time to take the posttest). The posttests were graded for correctness as a quiz for the quantum mechanics course. In addition, the upper-level undergraduate students were aware that the concepts discussed in the tutorial could also appear in future exams since the tutorial was part of the course material for the quantum mechanics course.

The QuILT was also administered in two consecutive years to post-graduate students ($N = 45$) who were simultaneously enrolled in the first semester of a post-graduate level core quantum mechanics course and a course for training teaching assistants. In the teaching assistant training class, the post-graduate students learned about instructional strategies for teaching introductory physics courses (e.g., tutorial-based approaches to learning). They first worked on the pretest (all students had sufficient time to take the pretest). The QuILT warm-up was given to the post-graduate students to work on at home. The post-graduate students worked through the QuILT in the teaching assistant training class to learn about the effectiveness of the tutorial approach to teaching and learning. They were given one week to work through the rest of the QuILT as a homework. Then, a posttest was administered to the post-graduate students in class after they had turned in the QuILT (all students had sufficient time to take the posttest). The post-graduate students were given credit for completing the pretest, QuILT, and posttest, but they were not given credit for correctness. The post-graduate students' scores on the posttest did not contribute to the final grade for the teaching assistant training class (which was a Pass/Fail course).

Here, we describe students' performance on questions related to some of the difficulties discussed earlier, i.e., ignoring interference phenomena in the Mach–Zehnder interferometer, claiming that the beam-splitter BS1 splits the photon into two parts and the two photons interfere at the detectors $D1$ and $D2$, making sense of "which-path" information in the MZI setup, and qualitatively reasoning about the setup in which one polarizer is placed in one of the paths of the MZI. Table 1 shows the percentages of students displaying the conceptual difficulties discussed earlier on the pre/posttest questions. We find that student difficulties were significantly reduced on the posttest after students worked on the QuILT. For example, Question 1 on the pre/posttest assessed students understanding of the classical interference of light in a situation in which a beam of light (instead of single photons) is sent through the MZI.

Table 1 Common difficulties and percentages of undergraduate students (UG) and post-graduate students (G) displaying them on the pretest/posttest questions involving single photons. The number of students who took the pretest does not match the posttest because some students did not work through the QuILT completely and their answers on the posttest were disregarded

Common difficulty	Pretest UG ($N = 44$)	Posttest UG ($N = 38$)	Pretest G ($N = 45$)	Posttest G ($N = 45$)
Q1 Ignoring interference phenomena	66	21	56	36
Q2 BS1 causes the photon to split into two parts and halves the photon energy	32	13	24	20
Q3 and Q4 Removing or inserting BS2 does not affect whether WPI is known and the probability of the detectors $D1$ and $D2$ registering photons	41	15	47	9
Q5 Claiming that one polarizer is no different than the setup with no polarizers except fewer photons arrive at the detectors and there is no change in the interference observed	34	10	36	13

In the first year of administration, 36 students were asked to explain why they agreed or disagreed with the following statement for the basic MZI setup shown in Fig. 1: "If the source produces light with intensity I, the intensity of light at each point detector $D1$ and $D2$ will be $I/2$ each". In the second year of administration, this question was modified and 53 students were asked to explain why they agreed or disagreed with the following statements for the basic MZI setup (Fig. 1) without a phase shifter: "If the source emits N photons one at a time, the number of photons reaching detectors $D1$ and $D2$ will be $N/2$ each". Both statements are incorrect because the MZI setup is such that there is completely constructive interference at $D1$ and completely destructive interference at $D2$. Therefore, the light (or single photons) from the U and L paths arrives completely in phase at detector $D1$ with intensity I (N photons arrive there) and arrives out of phase at $D2$ and no light (or photon) arrives there. However, Table 1 shows that 66% of the undergraduate students and 56% of the post-graduate students incorrectly agreed with this statement in the pretest, indicating that they did not appropriately account for the interference phenomenon taking place at the detectors. After working on the QuILT, this difficulty was reduced.

Question 2 on the pre/posttest assessed students' understanding of the wave nature of a photon. Students were asked to consider the following conversation between two students and explain why they agreed or disagreed with the statements:

Student 1: *"BS1 causes the photon to split in two parts and the energy of the incoming photon is also split in half. Each photon with half the energy travels along the U and L paths of the MZI and produces interference at the detectors."*

Student 2: *"If we send one photon at a time through the MZI, there is no way to observe interference at the detectors. Interference is due to the superposition of waves from the U and L paths. A single photon must choose either the U or L path."*

Neither student is correct because a photon does not split into two parts with half the energy of the incoming photon, but a single photon can be in a superposition of the U and L path states. 32% of the undergraduate students and 24% of the post-graduate students incorrectly agreed with student 1 in the pretest. Table 1 shows that after engaging with the QuILT, this difficulty involving the splitting of photons was significantly reduced.

Questions 3 and 4 on the pre/posttests evaluated student understanding of the role of beam-splitter BS2. Students were asked to describe whether interference is observed and the probability of the detectors $D1$ and $D2$ registering a photon in the MZI setups in which beam-splitter BS2 is removed or inserted. If BS2 is present, "which-path" information is unknown and both the U and L path components of the photon state are projected into each detector. Interference is observed at the detectors $D1$ and D2—detector $D1$ registers the photons with 100% probability. If BS2 is not present, "which-path" information is known and only the U path component is projected in detector $D1$ and only the L path component is projected in detector D2. The photons do not display interference and each detector registers the photons with 50% probability. In the pretest, 41% of the undergraduate students and 47% of the Ph.D. students incorrectly claimed that removing or inserting BS2 will not change the probabilities of the photon arriving at $D1$ and $D2$. This high percentage is consistent with the fact that these students did not acknowledge the wave nature and interference effects of single photons in response to other questions as well. Students often explicitly claimed that the photon behaves as a point particle and it would not matter whether BS2 was present or not—each detector would register the photon with 50% probability. Table 1 shows that in the posttest, students performed better. In addition, in the posttest, the majority of students correctly reasoned about questions 3 and 4 using the concept of "which-path" information.

Question 5 on the pre/posttest evaluated student understanding of the effect of placing one polarizer in one of the paths of the MZI. Students were asked to describe this situation qualitatively and to explain what percentage of photons would display interference. In the setup in which one polarizer is placed is one of the paths of the MZI, some of the photons display interference effects, whereas others do not. After working through the QuILT, the difficulty with how one polarizer affected the interference at the detectors was reduced (see Table 1).

4 Discussion and Implications

Students often struggle with quantum mechanics concepts partly because they are unintuitive and abstract. We have been developing research-based tools to help students learn the concepts better. In particular, we have been developing QuILTs to help students learn abstract quantum mechanics concepts. We performed a cognitive task analysis and conducted research on conceptual difficulties that students have with single-photon interference in the context of quantum optics experiments and used research as a guide to develop the TLS in the MZI QuILT. The QuILT went through several iterations based upon the investigation of student difficulties as well as the cognitive task analyses conducted by experts in the field. The performance on the posttest compared to the pretest suggests that the research-based QuILT on single-photon interference was effective in helping upper-level undergraduate and post-graduate students learn about quantum mechanics concepts in the context of quantum optics experiments. On the posttest, many students appropriately accounted for the wave nature of a single photon, were able to explain the interference phenomena of a single photon and correctly reasoned about MZI setups with polarizers.

Developing effective TLSs (e.g., QuILTs) involves drawing on the knowledge of content experts and educational researchers in the discipline as well as students' prior knowledge and difficulties. We found that after performing a cognitive task analysis from an expert perspective and discussing our analysis with several other physics faculty members, we still needed to refine the QuILT further. We learned several lessons during the development and refinement of the QuILT. For example, we needed to account for students' prior knowledge to help them bring to bear appropriate conceptual knowledge in the context of a Mach–Zehnder interferometer with single photons. Furthermore, we initially had an “expert blind spot” in that we thought that simpler MZI setups with only one polarizer would be easier for students to reason about than complex MZI setups with two or three polarizers. We found that this was not the case after analyzing students' written responses and conducting individual interviews and we needed to provide more scaffolding to students to help them to reason about a simple MZI setup (with only one polarizer). In addition, students sometimes interpreted terms incorrectly and we realized the need to clearly define terminology to help students get a better grasp of the meaning of new terms such as WPI in the QuILT. This issue involving terminology also occurs in introductory physics—everyday terms such as velocity, acceleration, momentum, energy, work, etc. do not have the same precise meaning as in physics and students must learn to differentiate how those terms are used in physics versus in everyday life. We also needed to think carefully about how to incorporate technology into the QuILT, keeping in mind that students may need to reason about a simpler theoretical model before engaging with a computer simulation that uses a more complex model. After an initial in-class implementation, we found that students still held deep alternative conceptions and we took these difficulties into account when refining the QuILT. In addition, students often mentioned in their written responses and interviews that they wanted to be able to integrate their conceptual understanding and quantitative reasoning. We took this concern into account and developed another component of the QuILT to help students connect concepts with quantitative reasoning.

In addition, it is also important to carefully contemplate when students should engage with particular TLSs within a broader learning progression. For example, the QuILT on single-photon interference could be situated in a broader sequence on two-state quantum systems in an advanced quantum mechanics course. However, this QuILT could also be situated in a sequence on wave-particle duality in a modern physics course. It is also important to consider the ordering of TLSs. For example, the QuILT on single-photon interference could be given before or after students learn about double-slit experiments involving single electrons. Certain sequences may better facilitate students' transfer of learning. Curriculum developers and researchers need to think about the most optimal ordering of TLSs in order to help students effectively transfer their learning to different contexts. Communication between content experts, educational researchers, students, and instructors is key to developing and implementing effective TLSs that support learning progressions.

Acknowledgements We thank the U.S. National Science Foundation for awards PHY-1505460 and PHY-1806691. We thank Albert Huber for developing the simulation that we adapted in the QuILT. We also thank students and faculty at the University of Pittsburgh (especially R. P. Devaty) and Andrew Daley and Daniel Oi at the University of Strathclyde, U.K. for helpful conversations during the development of the QuILT.

References

Alonzo A, Steedle J (2008) Developing and assessing a force and motion learning progression. Sci Educ 93:389–421

Andersson B, Bach F (2004) On designing and evaluating teaching sequences taking geometrical optics as an example. Sci Educ 89:196–218

Asfaw A et al. 2021 Building a Quantum Engineering undergraduate program. arXiv:2108.01311

Brown B, Singh C (2015) Development and evaluation of a quantum interactive learning tutorial on Larmor precession of spin Proc Phys Educ Res Con. https://doi.org/10.1119/perc.2014.pr.008

Brown B, Mason A, Singh C (2016) Improving performance in quantum mechanics with explicit incentives to correct mistakes. Phys Rev Spec Top Phys Educ Res 12:010121

Chi M (1994) Thinking aloud. The think aloud method: a practical guide to modeling cognitive processes. Academic Press, London

DeVore S, Singh C 2015 Development of an interactive tutorial on quantum key distribution. Proc Phys Educ Res Conf . https://doi.org/10.1119/perc.2014.pr.011

DeVore S, Singh C (2020) Interactive learning tutorial on quantum key distribution. Phys Rev Phys Educ Res 16:010126

Domert D, Linder C, Ingerman A (2005) Probability as a conceptual hurdle to understanding one-dimensional quantum scattering and tunneling. Eur J Phys 26:47

Emigh P, Passante G, Shaffer P (2015) Student understanding of time dependence in quantum mechanics. Phys Rev Spec Top Phys Educ Res 11:020112

Gire E, Price E (2015) Structural features of algebraic quantum notations. Phys Rev Spec Topics Phys Educ Res 11:020109

Hammer D (1994) Epistemological beliefs in introductory physics. Cogn Instr 12:151
Johnston I, Crawford K, Fletcher P (1998) Student difficulties in learning quantum mechanics. Int J Sci Educ 20:427–446
Jolly P, Zollman D, Rebello NS, Dimitrova A (1998) Visualizing motion in potential wells. Am J Phys 66:57–63
Keebaugh C, Marshman E, Singh C (2016) Developing and evaluating an interactive tutorial on degenerate perturbation theory. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2016.pr.041
Keebaugh C, Marshman E, Singh C (2018a) Investigating and addressing student difficulties with the corrections to the energies of the hydrogen atom for the strong and weak field Zeeman effect. Eur J Phys 39:045701
Keebaugh C, Marshman E, Singh C (2018b) Investigating and addressing student difficulties with a good basis for finding perturbative corrections in the context of degenerate perturbation theory. Eur J Phys 39:055701
Keebaugh C, Marshman E, Singh C (2019a) Improving student understanding of a system of identical particles with a fixed total energy. Am J Phys 87:583–593
Keebaugh C, Marshman E, Singh C (2019b) Improving student understanding of fine structure corrections to the energy spectrum of the hydrogen atom. Am J Phys 87:594–605
Keebaugh C, Marshman E, Singh C (2019c) Improving student understanding of corrections to the energy spectrum of the hydrogen atom for the Zeeman effect. Phys Rev Phys Educ Res 15:010113
Kohnle A et al (2010a) A new introductory quantum mechanics curriculum. Eur J Phys 35:015001
Kohnle A et al (2010b) Developing and evaluating animations for teaching quantum mechanics concepts. Eur J Phys 31:1441–1455
Lin S, Singh C (2009a) Categorization of physics problems by professors and students. Eur J Phys 31:57
Lin S, Singh C (2009b) Assessing expertise in quantum mechanics using categorization task. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.3266710
Lin SY, Singh C (2011) Using isomorphic problems to learn introductory physics. Phy Re Spec Top Phys Educ Res 7:020104
Lin SY, Singh C (2013) Using isomorphic problem pair to learn introductory physics: Transferring from a two-step problem to a three-step problem. Phys Rev Spec Top Phys Edu Res 9:020114
Lin SY, Singh C (2015) Effect of scaffolding on helping introductory physics students solve quantitative problems involving strong alternative conceptions. Phys Rev Spec Top Phys Educ Res 11:020105
Maries A, Lin SY, Singh C (2017a) Challenges in designing appropriate scaffolding to improve students' representational consistency: the case of a Gauss's law problem. Phys Rev Phys Educ Res 13:020103
Maries A, Sayer R, Singh C (2017b) Effectiveness of interactive tutorials in promoting "which-path" information reasoning in advanced quantum mechanics. Phys Rev Phys Educ Res 13:020115
Maries A, Sayer R, Singh C (2020) Can students apply the concept of "which-path" information learned in the context of Mach Zehnder Interferometer to the double slit experiment? Am J Phys 88(7):542–550
Maries A, Sayer R, Singh C (2015) Investigating transfer of learning in advanced quantum mechanics. Proceedings Physics Education Research Conference. https://doi.org/10.1119/perc.2015.pr.047
Marshman E (2014) Singh C Investigating student difficulties with time-dependence of expectation values in quantum mechanics. Proc Phy Educ Res Conf. https://doi.org/10.1119/perc.2013.pr.049
Marshman E, Singh C (2015a) Framework for understanding the patterns of student difficulties in quantum mechanics. Phys Rev Spec Top Phys Educ Res 11:020119
Marshman E, Singh C (2015b) Developing an interactive tutorial on a quantum eraser. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2014.pr.040
Marshman E, Singh C (2016) Interactive tutorial to improve student understanding of single photon experiments involving a Mach-Zehnder interferometer. Eur J Phys 37:024001

Marshman E, Singh C (2017a) Investigating and improving student understanding of quantum mechanics in the context of single photon interference. Phys Rev Phys Educ Res 13:010117
Marshman E, Singh C (2017b) Investigating and improving student understanding of the expectation values of observables in quantum mechanics. Eur J Phys 38:045701
Marshman E, Singh C (2017c) Investigating and improving student understanding of the probability distributions for measuring physical observables in quantum mechanics. Eur J Phys 38:025705
Marshman E, Singh C (2018) Investigating and improving student understanding of quantum mechanical observables and their corresponding operators in Dirac notation. Eur J Phys 39:015707
Marshman E, Singh C (2019) Validation and administration of a conceptual survey on the formalism and postulates of quantum mechanics. Phys Rev Phys Educ Res 15:020128
Marshman E, Singh C (2015) Student difficulties with quantum states while translating state vectors in Dirac notation to wave functions in position and momentum representations. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2015.pr.048
Marshman E, Singh C (2016) Student difficulties with representations of quantum operators corresponding to observables Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2016.pr.049
Mason A, Singh C (2009) Reflection and self-monitoring in quantum mechanics. Proc Phys Educ Res Conf https://doi.org/10.1063/1.3266713
Mason A, Singh C (2010) Do advanced students learn from their mistakes without explicit intervention? Am J Phys 78:760
Masters G, Forster M (1997) Developmental assessment, ACER assessment resource kit. Australian Council for Educational Research, Camberwell, AU
McDermott L, Shaffer P, Somers M (1994) Research as a guide for teaching introductory mechanics: an illustration in the context of the at wood's machine. Am J Phys 62:46–55
McDermott L (1996) University of Washington physics education group. Physics by inquiry: an introduction to the physical sciences. Wiley, New York
McDermott L, Shaffer P (1992) Research as a guide for curriculum development: an example from introductory electricity. Part I: Investigation of student understanding. Am J Phys 60:994–1003
McDermott L, Shaffer P (2002) University of Washington Physics Education Group. Tutorials in introductory physics, Upper Saddle River, NJ: Prentice-Hall
McKagan S, Perkins K, Wieman C (2008) Deeper look at student learning of quantum mechanics: the case of tunneling. Phys Rev Spec Top Phys Educ Res 4:020103
Meheut M, Psillos D (2004) Teaching-learning sequences: aims and tools for science education research. Int J Sci Educ 26:515–535
Michelini M, Zuccarini G (2014) University students' reasoning on physical information encoded in quantum state at a point in time. 2014 PERC Proceedings 2014:187–190
Michelini M, Ragazzon R, Santi L, Stefanel A (2020) Proposal for quantum physics in secondary school. Phys Educ 35:406
Müller R, Wiesner H (2002) Teaching quantum mechanics on an introductory level. Am J Phys 70:200–209
National Research Council. Learning Progressions. Taking science to school: learning and teaching science in grades K-8: The National Academies Press, Washington, DC, 213–250. https://www.nap.edu/read/11625/chapter/10
Piaget J (1978) Success and understanding. Harvard University Press, Cambridge, MA
Posner G, Strike K, Hewson W, Gertzog W (1982) Accomodation of a scientific conception: toward a theory of conceptual change. Sci Educ 66:211
Psillos D, Kariotoglou P (eds) (2015) Iterative design of teaching-learning sequences: introducing the science of materials in European schools. Springer, New York, NY
Reif F (1995) Millikan lecture 1994: understanding and teaching important scientific thought processes. Am J Phys 63:1
Sayer R, Maries A, Singh C (2015) Developing and evaluating a tutorial on the double-slit experiment. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2015.pr.070

Sayer R, Marshman E, Singh C (2016a) The impact of peer interaction on the responses to clicker questions in an upper-level quantum mechanics course. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2016.pr.071

Sayer R, Marshman E, Singh C (2016b) A case study evaluating just-in-time teaching and peer instruction using clickers in a quantum mechanics course. Phys Rev Phys Educ Res 12:02013

Sayer R, Maries A, Singh C (2017) Quantum interactive learning tutorial on the double-slit experiment to improve student understanding of quantum mechanics. Phys Rev Phys Educ Res 13:010123

Schneider M, LaPuma I (2001) A simple experiment for discussion of quantum interference and which-way measurement. Am J Phys 70:266

Schwartz D, Bransford J, Sears D (2005) Efficiency & innovation in transfer. Transfer of learning from a modern multidisciplinary perspective. Info Age, Greenwich, CT. pp 1–51

Siddiqui S, Singh C (2017) How diverse are physics instructors' attitudes and approaches to teaching undergraduate level quantum mechanics? Eur J Phys 38:035703

Singh C (2001) Student understanding of quantum mechanics. Am J Phys 69:885

Singh C (2002) When physical intuition fails. Am J Phys 70:1103

Singh C (2005) Transfer of learning in quantum mechanics. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.2084692

Singh C (2006a) Assessing and improving student understanding of quantum mechanics. Proc Phy Educ Res Conf. https://doi.org/10.1063/1.2177025

Singh C (2006b) Student difficulties with quantum mechanics formalism. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.2508723

Singh C (2007) Helping students learn quantum mechanics for quantum computing. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.2508687

Singh C (2008a) Interactive learning tutorials on quantum mechanics. Am J Phys 76:400–405

Singh C (2008b) Student understanding of quantum mechanics at the beginning of graduate instruction. Am J Phys 76:277

Singh C, Marshman E (2014a) Investigating student difficulties with Dirac Notation. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2013.pr.074

Singh C, Marshman E (2014b) Analogous patterns of student reasoning difficulties in introductory physics and upper-level quantum mechanics. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2013.inv.010

Singh C, Marshman E (2015a) Review of student difficulties in upper-level quantum mechanics. Phys Rev Special Top Phys Educ Res 11:020117

Singh C, Marshman E (2015b) Developing an interactive tutorial on a Mach-Zehnder interferometer with single photons. Proc Phys Educ Res Con. https://doi.org/10.1119/perc.2014.pr.056

Singh C, Marshman E (2016) Student difficulties with determining expectation values in quantum mechanics. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2016.pr.075

Singh C, Zhu G (2009) Cognitive issues in learning advanced physics: An example from quantum mechanics. Proce Phys Educ Res Conf. https://doi.org/10.1063/1.3266755

Singh C, Belloni M, Christian W (2006) Improving students' understanding of quantum mechanics. Phys Today 59:43–49

Singh C, Marshman E, Keebaugh C (2018) Investigating student difficulties with fine structure corrections to the energy of the hydrogen atom using degenerate perturbation theory. Proc Phys Educ Res Conf. https://doi.org/10.1119/perc.2017.pr.088

Singh C, Asfaw A, Levy J (2021) Preparing students to be leaders of the quantum information revolution. Phys Today. https://doi.org/10.1063/PT.6.5.20210927a

Singh C (2008) Assessing student expertise in introductory physics with isomorphic problems. I. Performance on a nonintuitive problem pair from introductory physics. Phys Rev Spec Top Phys Educ Res 4:010104

Singh C Assessing student expertise in introductory physics with isomorphic problems. II. Effect of some potential factors on problem solving and transfer. Phys Rev Spec Top Phys Educ Res 4:010105

Singh C, Marshman E (2015) Student difficulties with the probability distribution for measuring energy and position in quantum mechanics arXiv:1509.04081

Vygotsky L (1978) Mind in society: the development of higher psychological processes. Harvard University Press, Cambridge, MA

Wheeler J (1978) The "past" and the "delayed-choice" double-slit experiment. Mathematical foundations of quantum theory. Academic Press, New York, NY. pp 9–48

Wieman C (2015) Comparative cognitive task analyses of experimental science and instructional laboratory courses. Phys Teach 53:349

Wittmann M, Redish E, Steinberg R (2002) Investigating student understanding of quantum physics: spontaneous models of conductivity. Am J Phys 70:218

Zhu G, Singh C (2011) Improving students' understanding of quantum mechanics via the Stern-Gerlach experiment. Am J Phys 79:499–507

Zhu G, Singh C (2012a) Improving students' understanding of quantum measurement: I. Investigation of difficulties. Phys Rev Spec Top Phys Educ Res 8:010117

Zhu G, Singh C (2012b) Improving students' understanding of quantum measurement: II. Development of research-based learning tools. Phys Rev Spec Top Phys Educ Res 8:010118

Zhu G, Singh C (2012c) Improving students' understanding of quantum mechanics by using peer instruction tools. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.3679998

Zhu G, Singh C (2012e) Students' understanding of the addition of angular momentum. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.3680068

Zhu G, Singh C (2012f) Students' difficulties with quantum measurement. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.3680076

Zhu G, Singh C (2009) Students' understanding of Stern Gerlach experiment. Proc Phys Educ Res Conf. https://doi.org/10.1063/1.3266744

Zhu G, Singh C (2012d) Surveying students' understanding of quantum mechanics in one spatial dimension. Am J Phys 80:252

Zhu G, Singh C (2013) Improving student understanding of addition of angular momentum in quantum mechanics. Phys Rev Spec Top Phys Educ Res 9:010101

Zollman D et al (2002) Quantum mechanics for everyone: hands-on activities integrated with technology. Am J Phys 70:252

Initial Teacher Training

Fostering Physics Content and Pedagogy Learning in Future Physics Teachers via Student-Authored YouTube-Style Video Projects

Daniel Lawrence MacIsaac, Bradley Fennell Gearhart, André Bresges, Kathleen Ann Falconer, Florian Genz, Stefan Hoffmann, Lars Möhring, and Jeremias Damian Weber

Abstract We describe a curricular innovation for STEM teacher preparation—the use of video projects in undergraduate and graduate physics courses for future physics teachers at *SUNY Buffalo State.* US courses were adapted under the guidance of our colleagues' similar work at *Universität zu Köln* (Abbott D, Roberts A, MacIsaac D, Falconer K, Genz F, Hoffmann S, Bresges A, and Weber J, Adding Student Video Projects to Physics Courses, Phys. Teacher 2019 57 224.). Our students prepared end-of-course short "proof of concept" rough video vignettes of 5-10 min duration addressing both physics content and physics pedagogical topics. YouTube (MacIsaac D (2020a) [YouTube Video channel] Available from: https://www.youtube.com/user/danmacvids/. Accessed 15 Jan 2021) example videos are provided, resources for replicating our intervention are presented, and insights are shared.

1 Introduction

The use of video making by K-18 science students and STEM teaching students to learn science content has been reported since video cameras became available but have become widespread with the advent of *YouTube* and the proliferation of video recording smartphones (Abbott et al. 2019; Kearney 2009; Hechter and Guy 2010; Hoban et al. 2011; Pereira et al. 2012; Prud'homme-Genereux A 2016; Muller 2008; Coates et al. 2018). Since 2015, *SUNY (State University of New York) Buffalo State College* preservice and in-service STEM teachers taking physics (and some general science) undergraduate and graduate courses have been completing video

D. L. MacIsaac (✉) · B. F. Gearhart
Physics Department, State University of New York (SUNY) Buffalo State College, 1300 Elmwood Ave., Buffalo, NY 14222, USA
e-mail: macisadl@buffalostate.edu

A. Bresges · K. A. Falconer · F. Genz · S. Hoffmann · L. Möhring
Institut für Physikdidaktik, University of Cologne, Gronewaldstr. 2, 50931 Köln, Germany

J. D. Weber
Berufskolleg Werther Brücke, Bachstraße 17, 42275 Wuppertal, Germany

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_3

projects. These video projects (MacIsaac 2020a) were inspired and guided from efforts teaching STEM teachers in media classes at the *Institut für Physikdidaktik* of the University of Cologne.

Cologne's use of video in K-12 STEM teacher preparation is well-articulated in two semesters of media seminar courses that require explicitly analysis of science phenomena via well-established media techniques including slideshows, computer animation, stop motion, high-speed and slow-motion video, and possibly more advanced techniques like programming interactive simulations, creating iBooks, multimedia games and using lighting to create learning resources as project-based learning assignments. Some of these projects are extended to Baccalaureate or Masters projects and theses. These seminar courses were explicitly mandated in Cologne by revision of the teacher preparation curriculum to improve lesson didactics, creativity, and lesson design.

In the US efforts were much less formal, as we had to informally create room within traditional physics content for teachers' courses (via end-of-course projects which could optionally be video projects) or within popular but elective instructional technology courses for STEM teachers. Hence in the US instructors continuously group students for media expertise, provide standalone just-in-time resources, and sometimes even optional or informal instruction were needed for video making. Hence, most of the examples provided are from the German media seminar or Buffalo content topical physics for physics teachers' courses (Figs. 1 and 2a, b).

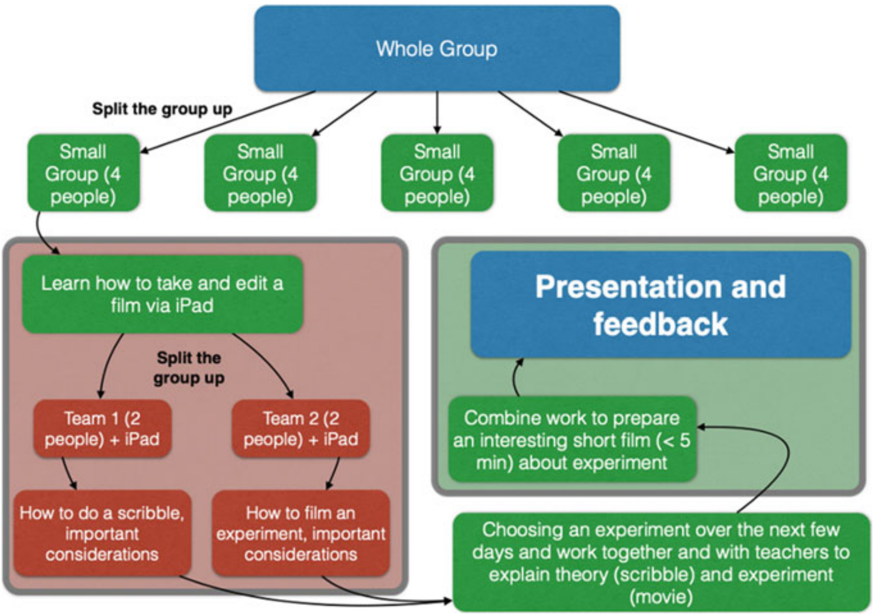
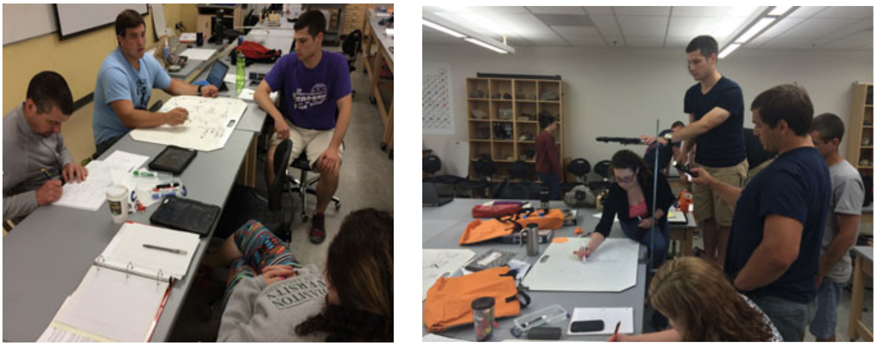


Fig. 1 One implementation of video making in the classroom, adapted after experiences at SUNY



(a) (b)

Fig. 2 **a** Students discussing the storyboard, **b** Students filming an animated text "scribble"

Finally, we must note that although student physics video project creation is here being discussed explicitly for physics teacher preparation courses, many of the authors use video projects as project-based learning tasks in our regular physics content course instruction for nonteachers, both in Germany and the US, and both for online and live face to face instruction (Abbott et al. 2019).

2 Goals

In this paper, we are looking at physics video making as a process rather than a product for the preparation of physics teachers, and we explicitly do not focus on any physics learning that may or may not result in the pupils of these students who might view the videos produced. We view video making as a reflective process where our students (who are future teachers) develop competencies appropriate for their own professional insight. In this fashion, student videos are like student lab reports, book reports, lesson plans, and other artifacts which MIGHT (rarely) prove useful in themselves but are primarily intended to foster learning, reflection, and skills development.

Our video making goals for teachers include: (1) developing teaching technical skills using video and media as representation and interaction tools—e.g., animation, dialogue, and video presentations, (2) learning physics content through reflectively planning and preparing visual representations of physics content to their classmates, (3) practicing physics instructional development using student learning outcomes literature and known learning difficulties to prepare videos for their own students, and (4) learning the pedagogy of physics by developing presentations for their teaching colleagues on instructional techniques, touchstone learning activities, and research-driven interventions.

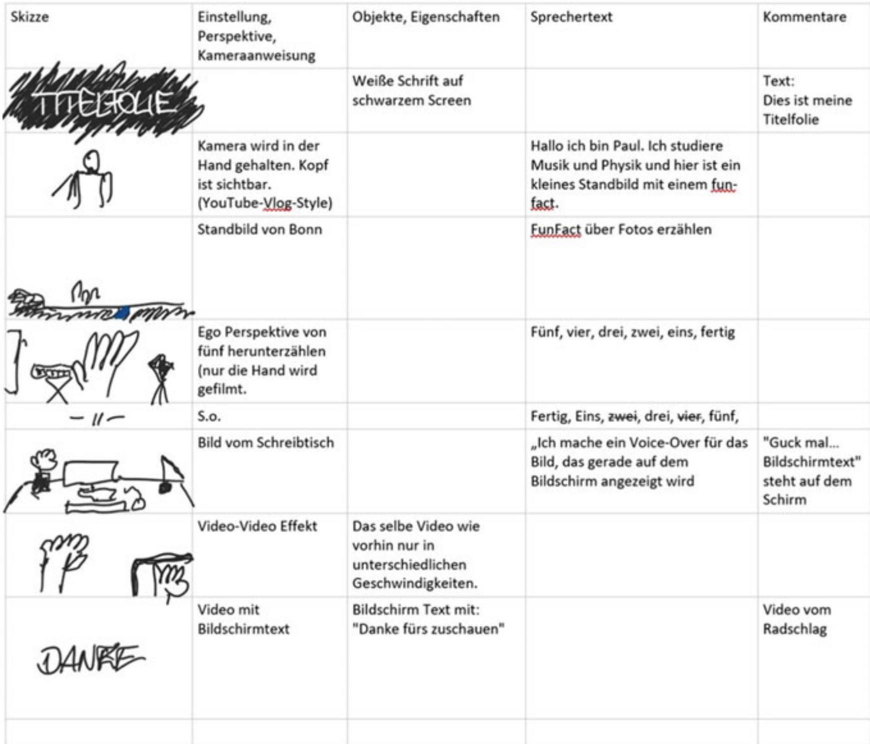
However, we do spend some time discussing the strong psychological limits of learning from videos by passively watching with our students. Muller (Muller, 2008) found “students learned very little from clear, concise, multimedia, especially low-knowledge learners” (p. 212). Muller advocates so-called misconception-based multimedia, where students are guided in small steps and where misconceptions are spelled out and challenged, to facilitate a deeper understanding. This insight is strongly counterintuitive for most teachers (or teacher students), who widely believe that explaining is teaching, and learning is memorizing. This IS an important insight for students on self-monitoring their own learning for effective practice. Muller has two short yet very helpful videos on the struggle to make effortful meaning which is characteristic of genuine learning that we regularly show to our students: *“Khan Academy and the Effectiveness of Science Videos”* includes nice review examples from projectile motion, and *“The Science of Thinking”* which focuses on invoking managed discomfort and mental effort for genuine learning (https://www.youtube.com/c/veritasium/).

3 Procedures

New York physics teaching students produce “rough cut” or “proof of concept” quality group video projects which comprise 10% of their course overall grade. A short email proposal (10% of project credit) is required about mid-semester, identifying a topic (often selected from a teacher-provided list), listing group members and roles, addressing safety, identifying and requesting materials, and other required resources, and stating a working title.

About 75% through the semester, a storyboard and annotated bibliography are due for another 10% of project credit. The video (which must contain mathematics, other multiple representations, and references in the video final credits) is presented (for 40% of project credit) in the last weeks of class, and classmates and instructors provide brief feedback. A short final reflective report (40%) is due at the final exam – the final report includes an abstract and references, final transcript and storyboard, and discussion of strengths, weaknesses, and suggestions for reshooting a second edition. A vanishing few of these videos are placed on YouTube with permission of all students.

Initially, we had no explicit instruction, activities, or lessons in video making in New York, simply assigning students the project after showing example videos (MacIsaac 2017a, 2016a, 2016b, 2017b, 2017c, 2020b, 2016). However, students’ prior experiences with video making proved highly variable—some had prior instruction in making and editing videos in grade school and college clubs and other courses, and others had never tried to make videos with their phones at all. Hence we developed not only examples but small assignments (sometimes optional in our more physics content-centric courses, sometimes not, as in STEM teaching media and technology courses) helping students with the video-making process. These assignments include the *Video Editing Assignment* (MacIsaac and Gearhart 2021), which has students make a very short 30 s long video requiring introductory and final credit title frames, requires that the student record a waist-up half shot performing a spoken 1–5 countdown with hand gestures, then playing back the countdown in a picture within a picture frame with sound edits, and finally including a voiceover accompanying a still frame. This short editing assignment dramatically improved the quality and impact of student-produced videos, and the *Video Editing Assignment* was subsequently adopted by the STEM teachers' media seminar in Cologne, wherein a nice example of synergy between NY and Germany, German students were also further required to storyboard their video editing assignment (Fig. 3). Notably, students in some of the more media explicit courses for STEM teachers experience some explicit instruction in video editing using a wide variety of low-cost or free editors. Others work on their videos without this instruction.



Skizze	Einstellung, Perspektive, Kameraanweisung	Objekte, Eigenschaften	Sprechertext	Kommentare
TITELFOLIE		Weiße Schrift auf schwarzem Screen		Text: Dies ist meine Titelfolie
	Kamera wird in der Hand gehalten. Kopf ist sichtbar. (YouTube-Vlog-Style)		Hallo ich bin Paul. Ich studiere Musik und Physik und hier ist ein kleines Standbild mit einem fun-fact.	
	Standbild von Bonn		FunFact über Fotos erzählen	
	Ego Perspektive von fünf herunterzählen (nur die Hand wird gefilmt.		Fünf, vier, drei, zwei, eins, fertig	
– // –	S.o.		Fertig, Eins, ~~zwei~~, drei, ~~vier~~, fünf,	
	Bild vom Schreibtisch		„Ich mache ein Voice-Over für das Bild, das gerade auf dem Bildschirm angezeigt wird	"Guck mal... Bildschirmtext" steht auf dem Schirm
	Video-Video Effekt	Das selbe Video wie vorhin nur in unterschiedlichen Geschwindigkeiten.		
DANKE	Video mit Bildschirmtext	Bildschirm Text mit: "Danke fürs zuschauen"		Video vom Radschlag

Fig. 3 Paul's storyboard of the video editing assignment from the Cologne teachers' media seminar

4 Products

At Buffalo State since summer of 2015, authors and colleagues have taught 12 sections of 22 undergraduate students each (264 total undergraduate preservice teachers) enrolled in *PHY104: Physics for K-8 Teachers*, and another 99 graduate students (mainly working STEM teachers in evening and online courses) in ten offerings of five graduate course titles: *PHY518: Waves and Optics for HS Teachers, PHY520: Modern Physics for HS Teachers, PHY522: Renewable and Sustainable Energy for HS Teachers, PHY620: Mechanics for HS Teachers,* and *PHY622: Electricity and Magnetism for HS Teachers*. These students were all assigned group end-of-course video projects, and a very small selection of these videos have been uploaded to *YouTube* (MacIsaac 2020a).

Example content videos from Buffalo physics teaching students include learning about elementary energy transformations (MacIsaac 2017a), electron–hole mechanisms in solar cells and LEDs (MacIsaac 2020b), and completing a half-life measurement experiment (MacIsaac and Half, 2016). Buffalo student physics pedagogical videos include using formative assessment (MacIsaac 2016a), developing kinematic equations via graphs (MacIsaac 2016b), and guiding student video making (MacIsaac 2017b, 2017c; MacIsaac and Gearhart 2021).

Another major goal of our Buffalo project has also been to create practical supporting materials such as guidelines documents, example videos, how-to videos, and rubrics that could serve as "plug and play" resources for other STEM content and pedagogy course faculty. Most importantly, we prepared and shared rubrics for both storyboard scoring (Fig. 4) and later final video scoring (Fig. 5) for optional use and articulation by instructors. Additionally, we had to conduct brief discussions and provide supplementary references to our students of what constituted fair use (https://fairuse.stanford.edu/overview/fair-use/what-is-fair-use) and citation (https://owl.purdue.edu/owl/research_and_citation/resources.html) of video and graphic works for video making.

The Buffalo rubric scales refer to meeting or exceeding "standards" throughout to match common STEM instructional language widely being adopted in the US. Standards are explicitly articulated within the New York State Science Learning Standards (http://www.nysed.gov/curriculum-instruction/science-learning-standards) which are themselves a lightly modified and extended version of the new US Next Generation Science Standards (NGSS—http://nextgenscience.org). Any instruction innovation must address standards in the US.

5 Conclusions and Lessons Learned

Our students are enthusiastic and have fun doing video projects, and they see video making as having strong face validity, even before the coronavirus pandemic. We incorporate insights into self-monitoring one's own learning via video watching

	Grading Scale			
Criteria	**Exceeded Standard**	**Meets Standard**	**Approaching Standard**	**Missing or Incomplete**
Overview	5 pts	4 pts	3 pts	0 pts
The storyboards should provide a clear overview of the video that will be produced that shows an appropriate level of planning and decision-making prior to recording	Provides a comprehensive and detailed overview of the video	Provides a "structural" overview of the video with some specific details	Provides a "skeletal" overview but lacks specific details of the video	Gives no indication of the theme or message of the video
Visual Elements	5 pts	4 pts	3 pts	0 pts
Each scene should be illustrated to give appropriate details about the objects, characters and environment in each scene	Visuals are colorful with comprehensive details that give a clear overview of each scene	Visuals are basic and give a satisfactory overview of each scene	Visuals give only a silhouetted overview of each scene	Missing or inappropriate
Written Elements	5 pts	4 pts	3 pts	0 pts
Each scene should have a written "narration" outlining the "flow" of each scene	"Narration" fully expresses the "flow" for each scene	"Narration" is basic and hints at the "flow" of each scene	"Narration" is mostly a static "snapshot" rather than expressing the "flow" of a scene	Missing or off topic
	Multiplier			
	1.00x	0.75x	0.50x	0.00x
Completeness: Approximately 2 storyboards per minute of video (at a minimum) representing each shift in focus	7+ storyboards	6 storyboards	4-5 storyboards	Fewer than 4 storyboards

Fig. 4 Buffalo video story board rubric

as part of this instruction. We focus on physics content and learning *process*, not *product*—we are trying to foster clear thinking and communication, not prepare Hollywood directors. Our students must be continuously refocused on the content and the learner, else they can get distracted by technical and stylistic issues (in-group humor, music, special effects). Students must manage their project time carefully supported by advanced planning and incrementally collected graded work by the instructor.

Collaborators and instruction in both Buffalo and Cologne have synergistically benefited from these physics video production efforts, and we are sharing knowledge, methods, and resources for physics learning video widely in the physics teaching community via workshops and publication (Abbott et al. 2019).

Physics video learning projects have particularly become impactful since the pandemic has strongly driven physics and STEM instruction online, and these projects are well-suited to students working in separate locations and sharing work via computer. We do not expect instructional use of video to disappear post-pandemic, given the growth in the power and impact of video technology upon our students' lives.

	Grading Scale			
Criteria	**Exceeds Standard**	**Meets Standard**	**Approaching Standard**	**Missing or Incomplete**
Content	40 pts	36 pts	26 pts	20 pts
This section evaluates the accuracy and relevancy of the content presented	The content presented is accurate using multiple representation and expands upon concepts learned throughout the course	The content presented is accurate using multiple representations and concepts learned throughout the course	The content presented is mostly accurate and/or shows only several representations with limited course coverage	The content presented contains multiple errors and/or uses a single representation or concept learned throughout the course
Audio/Video Editing	10 pts	8 pts	6 pts	0 pts
This section evaluates the use of editing to create flow and consistency throughout the video	Editing is pseudo-professional using a variety of techniques to provide flow and balance across the video	Editing is advanced and establishes a sense of flow and balance across the video	Editing is basic but does not support flow and balance across the video	No editing is evident
Theme	10 pts	8 pts	6 pts	0 pts
This section evaluates the coherence of the material presented to the assigned topic	The theme is coherent and present in each facet of the video	Most parts adhere to the overall theme with some minor deviations	The theme is difficult to discern and appears to be a collage of ideas	No discernible theme
Storytelling	10 pts	8 pts	6 pts	0 pts
This section evaluates the logical progression and organization of the material presented	Arrangement of material enhances explanation and viewer comprehension	Arrangement of material supports explanation and viewer comprehension	Arrangement of material is distracting to explanation and viewer comprehension	Arrangement of material negatively impacts explanation and viewer comprehension
Video Integration and Representation	15 pts	12 pts	9 pts	7 pts
This section evaluates the appropriate use of media elements to create a dynamic and rich visual experience	Advanced use of media to create a dynamic and rich visual experience	Uses visual elements that are not possible, or easily conveyed, by "pencil and paper"	Uses media to express concepts and ideas not easily represented via static images	Does not make appropriate use of video (For example: Narrated slideshow or animated writing)
Reference Card	10 pts	8 pts	N/A	Redo Assignment
This section evaluates the use of and references to others' intellectual property. See Fair Use guidelines* and information on scholarly citations**	Use of non-original content (video, images, sound, etc.) is minimal. Borrowed content has complete URLs. Three or more properly formatted citations to relevant scholarly work are included	Minor infractions	N/A	Major infractions (including copyright infringement)
Professionalism	5 pts	4 pts	N/A	Redo Assignment
This section evaluates the use of socially and culturally sensitive language and situations throughout the video	Complete compliance	Minor infractions	N/A	Major infractions
	Multiplier			
Video Length	1.00x	0.90x	0.65x	0.50x
This section evaluates if the video meets the time requirements (3-5 minutes)	Meets the 3-5 minute guideline	Exceeds 5 minutes (5:01-5:59 minutes)	Falls short by less than a minute (2-2:59 minutes)	Less than 2 minutes or greater than 6 minutes

Fig. 5 Buffalo final video extended scoring rubric

Acknowledgements This work is partially funded by the "Future Strategy for Teacher Education" (ZuS) at the University of Cologne as part of the "Qualitätsoffensive Lehrerbildung", a joint initiative of the Federal Government and the länder that aims to improve the quality of teacher training. The program is funded by the Federal Ministry of Education and Research. Some of the Buffalo State work was supported by the State University of New York (SUNY) Innovative Instruction Technology Grants (IITG) program. The authors are responsible for the content of this publication.

References

Abbott D, Roberts A, MacIsaac D, Falconer K, Genz F, Hoffmann S, Bresges A, Weber J (2019) Adding student video projects to physics courses. Phys Teacher 57:224

Coates RL, Kuhai A, Turlej LZJ, Rivlin T, McKemmish LK (2018) Phys filmmakers: teaching science students how to make YouTube-style videos. Eur J Phys 39:015706

Hechter RP, Guy MD (2010) Promoting creative thinking and expression of science concepts among elementary teacher candidates through science content movie creation and showcasing. Contemp. Issues Technol. Teach. Educ. 10(4):411

Hoban G, Loughran J, Nielsen W (2011) Slowmation: pre-service elementary teachers representing science knowledge through creating multimodal digital animations. J Res Sci Teach 48(9):985

Kearney M (2009) Towards a learning design for student-generated digital storytelling. In: The future of learning design conference. University of Wollongong Research Online

MacIsaac D (2016a), *Half Life Beta Version* [Video]. 2016a, Available from https://youtu.be/rEu1JePXXwI. Accessed 15 Jan 2021

MacIsaac D (2016b) Using formative assessments in the physics classroom V2 [Video]. Available from https://youtu.be/PHOZRy__Yms. Accessed 15 Jan 2021

MacIsaac D (2016c) Linearization and the kinematics equations V2 [Video]. Available from https://youtu.be/ODvLr_zkfwE. Accessed 15 Jan 2021

MacIsaac D (2017a) Electric water [Video]. Available from https://youtu.be/FpC_cxF1QNg. Accessed 15 Jan 2021

MacIsaac D (2017b) Law of reflection sample video project [Video]. Available from https://youtu.be/9ozpJUBV3R0. Accessed 15 Jan 2021

MacIsaac D (2017c) Breaking the 4th wall: making a physics video [Video]. Available from https://www.youtube.com/watch?v=iecXeKgdnuU. Accessed 15 Jan 2021

MacIsaac D (2020a) [YouTube Video channel]. Available from: https://www.youtube.com/user/danmacvids/. Accessed 15 Jan 2021

MacIsaac D (2020b) PHY522 flashlight overview: PN junctions, PV cells and LED function [Video]. Accessed from https://youtu.be/RZdUF2bq54w. Accessed 15 Jan 2021

MacIsaac D (2021) Brad Gearhart video editing assignment [Video]. Available from https://youtu.be/KZ2MyQrVpdc. Accessed 15 Jan 2021

Muller DA (2008) Designing effective multimedia for physics education. Ph.D. dissertation, School of Physics, University of Sydney, Australia

Pereira MV, de Souza Barros S, de Rezende Filho LA, de A. Fauth LH (2012) Audiovisual physics reports: students' video production as a strategy for the didactic laboratory. Phys Educ 47(1):44

Prud'homme-Genereux A (2016) Student-produced videos for the flipped classroom. J Coll Sci Teach 45(3):58

How Do Prospective Primary Teachers Exploit Typical Astronomy Textbook Images?

Italo Testa, Silvia Galano, and Marisa Michelini

Abstract Previous work has shown that astronomy textbook images can be difficult for students to understand. The main reason for such difficulty lies in the fact the astronomical images are two-dimensional representations of three-dimensional phenomena. As such, some features of the phenomena may remain difficult for the students to understand. However, few studies have investigated whether teachers are aware of such students' difficulties. In this paper, we will present the extent to which prospective primary teachers are aware of the difficulties in reading such images and how they plan to use them in their practice. Implications for teacher training will be briefly discussed.

1 Introduction and Aims

The increasing use of pictures or graphical representations in science teaching raises the issue of understanding the so-called 'visual language', which features functions and structures similar to those of verbal language (Halliday 1978). The knowledge of the visual language is necessary to communicate effectively and helps to acquire new information. Within science areas, astronomy is a discipline historically grounded on images. School textbooks feature a plenty of Earth photographs, Sun-Moon-Earth system diagrams and diagrams (as the H-R map) to explain related scientific concepts. Beautiful images of the Moon or of close stars are also used to stimulate students' interest and sense of wonder and motivate them towards science-related careers. Moreover, astronomers and astrophysicists intensively use high-definition photographs obtained from Earth telescopes and satellites (Hubble Space Telescope,

I. Testa · S. Galano (✉)
Department of Physics 'E. Pancini', University Federico II of Naples, Naples, Italy
e-mail: silvia.galano@unina.it

I. Testa
e-mail: italo.testa@unina.it

M. Michelini
Dipartimento di Scienze Matematiche, Informatiche e Fisiche, University of Udine, Udine, Italy

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_4

Hipparcos, Spitzer) to study the morphology of a sky sector, to measure the period of luminosity changes of complex stellar systems as the Cepheids or double stars, or to determine the distance of a given galaxy using spectroscopy methods. Finally, images are increasingly exploited in many educational software packages (Starry Nights, Celestia, Observer).

However, astronomy is also a content area where students frequently hold a variety of alternative conceptions (Bailey and Slater 2003). Many studies have analysed students' difficulty in understanding astronomical phenomena, but only a few studies have focused on students' difficulty with the interpretation of diagrams and iconic representations of these phenomena. Most research studies generically point out that representations of astronomical phenomena can be misleading because they are often complex, ambiguous and necessarily represent only a specific view (e.g. top or side) being the 3D represented phenomena forced into a 2D depiction (Ojala 1992; Kikas 1998; Mishra 1999; Pena and Quilez 2001). Some authors (Vosniadou 2010) suggested that typical textbook representations of astronomical phenomena, as, for instance, those representing the motion of the Earth around the Sun, are conceptual models and, as such, can be difficult for the students to interpret. The reason is twofold: (i) graphical representations require a domain-specific knowledge; (ii) graphical representations are often not consistent with the perceptually based models that students have created using their everyday experience. It seems therefore crucial that teachers help students correctly read such textbook images. However, until now, few studies have focused on the extent to which teachers are aware of the student's difficulties in reading these images and on their use in the teaching practice. To address this issue, we set a study based on the following research questions:

RQ1. Which graphical elements of typical astronomy textbooks are identified by teachers as difficult to read for the students?

RQ2. On which graphical elements of typical astronomy textbooks teachers focus to explain the represented phenomenon?

2 Theoretical Framework

To answer our research questions, we used the semiotic-based theoretical framework by Kress and van Leeuwen (1996). The framework assumes that students need to know how to decode the specific visual language of an image so that they can correctly interpret its content (Roth et al. 1999). For instance, in some studies, it has been found that students consider it more useful, for the understanding of a scientific concept, diagrams and not photographs, which sometimes hide implicit messages not easily decodable. Other studies show that images may produce an effect contrary to that intended by the authors themselves, unavoidably altering the traditional function attributed to images of helping the explanation of a concept (Reid 1990; Reid and Beveridge 1990). The framework also predicts that combining together different types of visual representations may generate difficulties in the interpretation of the message encoded within an image.

Prior work (Pintò 2002) suggests that the following graphical elements may lead to difficulties when reading and interpreting documents containing different types of visual representations:

1. Elements representing both real-world and schematic or symbolic entities;
2. Elements to be selected or conceptually highlighted in relation to textual/graphical features which make them salient, or do not make them salient;
3. Elements that require appropriate readings of symbols and which contain examples of synonymy, homonymy and/or polysemy of symbols;
4. Presence/absence of verbal elements to be read as an important part of the image, such as captions;
5. Presence of two or more conceptually related images;
6. Compositional structures that require the interpretation of spatial distributions and of different representational structures.

The framework allowed to explain well-known difficulties of students in the interpretation of kinematic graphs (Testa et al. 2002), of energy diagrams (Stylianidou 2002) and of images in geometrical optics containing light rays (Viennot 1996). In the following section, we describe how we used the framework in our study.

3 Methods

3.1 Sample and Instructional Context

Our sample included 123 students involved in a Physics Education and Educational Lab course in the third year of the Master course for prospective primary teachers at the University of Udine. This Master course is a 5-year university course that allows students to get a degree that is necessary to teach at primary schools (6–10 years old). The course exploits research-based materials and aims at developing a flexible Pedagogical Content Knowledge (PCK) by means of the Metacultural, Experiential, Planning and Situated (MEPS) formative approach (Michelini 2020). The MEPS teaching/learning approach consists in the analysis and comparison of multiple educational proposals on the following topics: measurement, density and mass, motion, forces and balance, astronomy, thermal phenomena, energy, fluids, optical phenomena, spectroscopy, sound, magnetic phenomena, electrical phenomena and direct current circuits. For each thematic proposal, the analysis aims to identify the foundational nuclei, the addressed learning knots, the rational or conceptual approach of the educational proposal, the active role of the learner in the different phases of the proposed paths, the learning environments and the relationships with other disciplines. The MEPS approach allows also to analyze contents, strategies, methods and teaching tools of the educational proposals. Using the MEPS approach, during the course, the prospective primary teachers: (i) identify the subject content knowledge of the proposals; (ii) compare the proposals for primary school students with those of upper levels physics textbooks (‘teacher knowledge’ part) and (iii) explore possible ways to address specific physics topics with children (‘doing with children’ part). The adopted theoretical framework is the Model of Educational Reconstruction (MER) (Duit et al. 2012). The analysis of the main conceptual difficulties of a specific topic is part of the way in which the professional teacher education is addressed by means of research papers and/or experiencing research problems, as in this case, for the visual representations in astronomy. After the course, the prospective teachers are expected to design teaching activities (planning part) suitable for the classroom implementation with primary school children. For this study, two three-hour meetings were specifically dedicated to images and to astronomy textbook representations. The Kress & van Leeuwen framework was presented as a tool to decide whether to use or not to use a given textbook representation.

3.2 Instrument

In order to answer our research questions, we asked participating prospective teachers to examine eight images targeting basic astronomical phenomena: night and day (1 image), change of seasons (3 images), Moon phases (3 images) and eclipses (1 image). All the images used in this study were selected from common Italian textbooks used in primary, middle and secondary schools.

For this study, we focus on seasonal changes, in particular on the representation in Fig. 1 (Testa et al. 2014). First, we note that this image has a complex compositional structure. In the attempt to reproduce in a 2D perspective significant elements of a three-dimensional system, it shows the orbit of the Earth and the plane on which it lies on from a slightly tilted perspective, introducing a false eccentricity (Earth’s orbit has an eccentricity near to 0). Moreover, the four ‘Earths’, namely four positions of the Earth, which mark equinoxes and solstices and represent seasons, are shown together in the same diagram, even if they refer to different times of the year. In addition, some verbal elements, as the indication of the ‘line of equinoxes’, the shading representing regions on the Earth not illuminated by the Sun, the presence of arrows and of the red lines representing Earth-Sun distance at equinoxes and solstices, can confuse students. Finally, we note that the Earth-Sun relative dimensions are not in scale. We resume in Table 1 the graphical elements of the image that may cause difficulties and their classification according to the adopted theoretical framework.

To answer our research questions, we designed the following open questions:

- Which graphical elements (e.g. lines, arrows, etc.) can be difficult to understand for students?
- Which graphical elements (e.g. lines, arrows, etc.) can reinforce students’ misconceptions about the represented astronomical phenomena?
- Which graphical elements (e.g. lines, arrows, etc.) can be helpful for students to understand the represented astronomical phenomena?

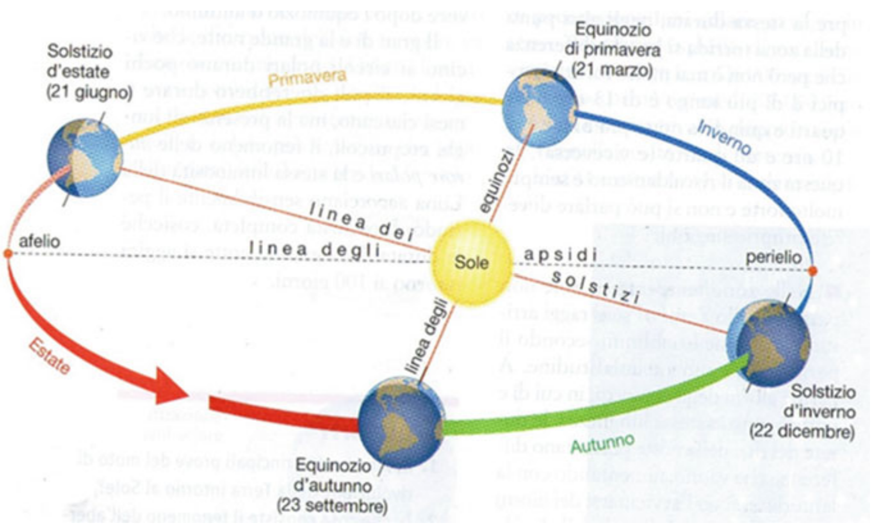


Fig. 1 Textbook image about seasonal changes used in the present study. Image taken from '*Il Globo terrestre e la sua evoluzione*', by Elvidio Lupia Palmieri and Maurizio Parotto (sixth edition) and used courtesy of Zanichelli Publishing Company. See also (Testa et al. 2014) for more details

Table 1 List of graphical elements of Fig. 1 that may cause interpretation difficulties

Graphical element	Type of difficulty (Pintò 2002)
False eccentricity	Compositional structures that require the interpretation of spatial distributions and of different representational structures
Four Earths	Presence of two or more conceptually related images
Summer solstice, aphelion, perihelion, winter solstice, …	Presence of verbal elements to be read as an important part of the image, such as captions
Arrows representing Earth's motion	Elements that require appropriate readings of symbols and which contain examples of synonymy, homonymy and/or polysemy of symbols
Line representing Earth's axis Lines representing Earth-Sun distance Shading	Elements to be selected or conceptually highlighted in relation to textual/graphical features which make them salient or do not make them salient

- Which graphical elements (e.g. lines, arrows, etc.) can help students to overcome possible misconceptions about the represented astronomical phenomena?

Table 2 Categories used to analyze prospective teachers' responses

Category of response	Description
No identification	No reference in the response to the specific graphical element
Incorrect identification	A graphical element that may present difficulties is indicated as helpful to understand the phenomenon
Partial identification	A graphical element that may be both helpful or difficult to read is indicated as only helpful or only difficult
Correct identification	A graphical element is correctly identified as difficult or helpful to understand the phenomenon

3.3 Data Analysis

For each image, we categorized the prospective teachers' responses to the open questions using a constant comparative method (Strauss and Corbin 2008). Two researchers analysed independently the whole data set, generating for each question a suitable number of categories to fit the students' responses. Then, we collapsed the initial categories into four macro-categories (see Table 2).

Two researchers reviewed again the students' responses to check the categorization. Inter-rater reliability was evaluated obtaining at the end of the process a satisfactory level of 0.80.

4 Results and Discussion

Overall, 492 responses were analyzed. Figure 2 reports, for each graphical feature of the textbook image in Fig. 1, the frequency of the macro-categories 'no/incorrect' identification and 'partial/correct' identification.

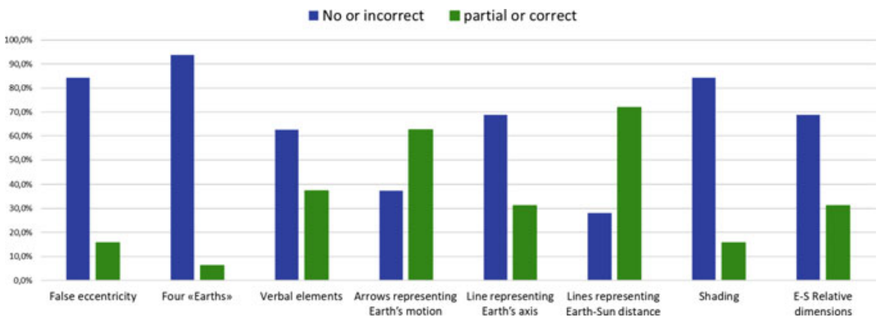


Fig. 2 Frequency of the macro-categories no/incorrect identification and partial/correct identification of the prospective primary teachers' responses about the image in Fig. 1

Examples of each category are reported in Table 3 for some of the graphical features of the image in Fig. 1.

From the analysis of the prospective teachers' responses, it seems that the image graphical characteristics were mostly considered a help to understand correctly the seasonal changes. In particular, the presence of symbols, as the arrows that represent the direction of revolution, were judged as particularly helpful to understanding that seasons are a periodic phenomenon but disregarding the possible confusion due to the presence of an arrow that may be interpreted for instance as the velocity of the Earth around its orbit. Similarly, also the verbal elements as the words 'Spring equinox' 'Winter solstice' and the exaggerated ellipticity of the Earth's orbit were mostly considered helpful hints for the pupils to support the argument that the orbit is not circular. Only rarely elements as the shaded areas, the lines and the verbal elements were identified as difficult to read. Such evidence suggests that prospective teachers may use the textbook images in their practice only as a tool to enchant pupils and not as a pedagogical help to improve understanding of the represented phenomenon. However, we also note that the involved prospective teachers correctly identified the lines representing Earth-Sun distance as a potential issue that may reinforce the idea that Sun-Earth distance is important in the seasonal change phenomenon. Similarly, few prospective teachers pointed out that such lines may be perceived by young pupils as 'real' lines.

5 Implications for Teacher Training

From the above results we infer that to help students acquire a more accurate knowledge of elementary astronomical phenomena, teacher training courses should focus on how textbook images are used in the teaching practice of astronomy. In particular, teachers should become familiar with images that may favour the development of spatial reasoning and modelling skills, focusing on geometry and underlying mechanism of the phenomenon, especially at primary and middle school levels. Moreover, our data suggest that training courses should help prospective teachers become aware of the following ways to overcome students' difficulties in reading images:

- Images with iconic elements of different types or with different representations to relate to each other can be difficult to read. Representations should be kept separate, in different frames, in order to overcome this problem;
- If used, symbolic verbal or iconic elements with possible different meanings must be well indicated and integrated within the image; in addition, it would be appropriate to provide reading keys for correctly decoding the image;
- The presence of hidden/implicit graphical features should be limited, in particular, the overlapping of time and space sequences;
- Images with too many graphical elements representing different scientific concepts or ideas in the same image should be avoided.

Table 3 Categorization of example prospective primary teachers' responses about the image in Fig. 1

Category of response	Example response
Incorrect identification	The graphical elements that might help correct misconceptions are: the Earth's orbit is elliptical, so perihelion and aphelion have different distances from the Sun (*False eccentricity).* The orbit drawn could be misleading: it seems to be a circle seen in perspective rather than an ellipse, as it should be. The Sun should also be in one of the two fires, while it appears not far from the centre (*False eccentricity*). The elements that can help students overcome some of their possible misconceptions related to the phenomenon represented are the red lines thanks to which children can see that the Earth-Sun distance is not in itself an explanation of the change of seasons. In fact, they can see that in summer the Sun is at the maximum distance from the Earth (*Lines representing Earth-Sun distance*).
Partial identification	The coloured arrow is a graphic element that helps students understand the direction of the Earth's revolution motion around the Sun (*Arrows representing Earth's motion*). Not all the areas of the Earth are equally illuminated by the Sun and depending on the position of the planet in orbit. This can help pupils to overcome the idea that the Earth is illuminated in the same way throughout its surface (*Shading*). The four 'Earths' around the orbit can help students understand the correspondence between the four seasons and the position of the Earth along the orbit (*Four 'Earths'*).
Correct identification	The lines of the solstices and equinoxes may be more complex to interpret, also because they are inserted in a very rich image. There are many important aspects to consider and analyse (*Lines representing Earth-Sun distance*). The graphic element that can be complicated and excessively complex to interpret is the red arrow that starts from the summer substitute detaches and then resumes its path along the ellipse, moreover, it is difficult to understand the simultaneous effect of Earth's rotation and its inclination that remains too abstract (*Arrows representing Earth's motion*). A graphic element that can help students is the axis of the Earth which is always represented equally inclined. This representation reinforces the idea that it doesn't move and, as a result, children overcome their mistaken idea that the axis can move (*Lines representing Earth's axis*). A graphic element that could reinforce misconceptions about the phenomenon of alternating seasons is the size of the Sun which is represented as large as the Earth is represented (*Earth-Sun relative dimensions*). Equinoxes (spring and autumn) and solstices (in summer and winter) are explicitly indicated without specifying that they apply only to the Northern Hemisphere (*Verbal elements*).

Finally, our investigation raises other questions, which may be useful to investigate further. All the images discussed in the tasks were taken from textbooks widely used in high schools. These texts nowadays focus a lot on the visual communication aspect of scientific concepts. These images are, therefore, in principle, the most attractive because they are expressly built for students. The analysis of prospective teachers' responses shows that they often hold the same misconceptions about the target astronomical phenomena of their pupils. Hence, we infer that the involved prospective teachers interpret the information featured in the images through theoretical lenses that are very similar to those of their future pupils. Due to the nature of the concepts addressed, these lenses are essentially geometrical models that are incorrect or inadequate for the targeted phenomena, such as for example: the ellipse (Earth's orbit), the alignment between solid bodies (Sun and Earth), the disposition of lines and arrows in a plane (Earth-Sun distance and revolution). Although they are in principle neutral, when applied to specific contexts such as astronomy, these models can lead students and prospective teachers as well to incorrect reasoning. This evidence is consistent with the prior results that suggest that the difficulties of students in explaining some common astronomical phenomena were mainly related to difficulties with geometry. As a result, teachers should spend more time in discussing with students about these models and of the 'a priori' meaning that students themselves can attribute to images based on the adopted models. As suggested by many responses of the prospective teachers in the sample, images are often considered easy to read with the meaning that can be inferred simply by looking at them. Similarly, many teachers in our sample judged positively the use of attractive graphical elements (e.g. the colour of the orbit, which, on the contrary, can impair the correct interpretation of the image.

In conclusion, while being limited to one image, the study in this paper may be a useful starting point for researchers who intend to build training courses about astronomical images, both printed and virtual, such as those that can be found in the web or used in well-known simulation programmes such as Stellarium or Celestia.

In the next step of our research, we will finish our analysis in order to triangulate data concerning different astronomical phenomena.

References

Bailey JM, Slater TF (2003) A review of astronomy education research. Astron Educ Rev 2:2

Duit R, Gropengießer H, Kattmann U, Komorek M, Parchmann I (2012) The model of educational reconstruction—a framework for improving teaching and learning science. In: Jorde D, Dillon J (eds) Science education research and practice in Europe. Cultural perspectives in science education, vol 5. Sense Publishers, Rotterdam. https://doi.org/10.1007/978-94-6091-900-8_2

Halliday MAK (1978) Language as social semiotic. The social interpretation of language and meaning. Edward Arnold Publishers, London

Kikas E (1998) Pupils' explanations of seasonal changes: age differences and the influence of teaching. Br J Educ Psychol 68:505. https://doi.org/10.1111/j.2044-8279.1998.tb01308.x

Kress G, van Leeuwen T (1996) Reading images: the grammar of the visual design. Routledge, London and New York. ISBN: 9780415672573

Michelini M (2020) Dialogue on primary, secondary and university pre-service teacher education in physics. In: Guisasola J, Zuza K (eds) Research and innovation in physics education: two sides of the same coin. Challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-030-51182-1_3

Mishra P (1999) The role of abstraction in scientific illustration: implications for pedagogy. J Vis Lit 19:139. https://doi.org/10.1080/23796529.1999.11674549

Ojala J (1992) The third planet. Int J Sci Educ 14:191. https://doi.org/10.1080/0950069920140207

Pena BM, Quilez MJG (2001) The importance of images in astronomy education. Int J Sci Educ 23:1125. https://doi.org/10.1080/09500690110038611

Pintò R (2002) Introduction to the science teacher training in an information society STTIS project. Int J Sci Educ 24:227–234. https://doi.org/10.1080/09500690110078888

Reid D (1990) The role of pictures in learning biology: Part 2, picture-text processing. J Biol Educ 24:251. https://doi.org/10.1080/00219266.1990.9655153

Reid D, Beveridge M (1990) Reading illustrated science texts: a micro-computer based investigation of children's strategies. Br J Psychol 60:76. https://doi.org/10.1111/j.2044-8279.1990.tb00923.x

Roth W-M, Bowen GM, McGinn MK (1999) Differences in graph-related practices between high school biology textbooks and scientific ecology journals. J Res Sci Teach 36:977. https://doi.org/10.1002/(SICI)1098-2736(199911)36:9<977::AID-TEA3>3.0.CO;2-V

Strauss A, Corbin J (2008) Basics of qualitative research (3rd ed): techniques and procedures for developing ground theory. SAGE, London. https://doi.org/10.4135/9781452230153

Stylianidou F (2002) Analysis of science textbook pictures about energy and pupils' readings of them. Int J Sci Educ 24–3:257–283. https://doi.org/10.1080/09500690110078905

Testa I, Monroy G, Sassi E (2002) Students' reading images in kinematics: the case of real-time graphs. Int J Sci Educ 24:235. https://doi.org/10.1080/09500690110078897

Testa I, Leccia S, Puddu E (2014) Astronomy textbook images: do they really help students? Phys Ed 49:332–343. https://doi.org/10.1088/0031-9120/49/3/332

Viennot L (1996) *Raisonner en physique: la part du sens commun*. De Boeck, Louvain la Neuve

Vosniadou S (2010) Instructional considerations in the use of external representations: the distinction between perceptually based depictions, and pictures that represent conceptual models, In: Verschaffel L et al (eds) Use of representations in reasoning and problem solving. Routledge, New York/Abingdon, pp. 36–54. ISBN: 9780415556743

Teaching Physics in Kindergarten and Primary School: What Do Trainee Teachers Think of This?

Angelika Pahl

Abstract Physics training for kindergarten and primary-school teachers should consider the trainee teachers' attitudes, perceived capability and preconceptions with regard to physics because it is known that the latter can influence their future teaching behaviour. Therefore, in this study, the status quo of beginners in teacher training for the kindergarten and primary-school level was investigated, analysed and evaluated. A survey was conducted with 269 trainee teachers to detect characteristics regarding different content areas of natural and social sciences. The results demonstrated that social-ethical, geographical, historical and biological topics are more popular than physical-technical topics. At the same time, self-efficacy beliefs concerning physics education topics are low. In addition, male subjects had slightly more affinity for and confidence in teaching physics than female subjects. Content analysis of questions with an open answer format showed that several trainee teachers had difficulty giving a complete and systematic response when asked to name suitable physics topics for kindergarten and primary-school students. The high number of correctly named topics correlated significantly with high scores on characteristics of affection, experience and perceived capability with regard to physics.

1 Introduction

In teacher education for physics in kindergarten and primary school, we face the challenge that trainee teachers tend to have little interest in physics and a poor academic self-concept with respect to the subject. Accordingly, they often have an aversion to teaching physics topics. These findings indicate that a negative personal attitude towards a subject can influence one's work-related attitude, such as primary teachers' attitude toward teaching physics (Pahl and Tschiesner 2022; Tschiesner and Pahl 2019; Pendergast et al. 2017; Kleickmann 2015; Appleton 2007; Hacieminoglu 2016).

A. Pahl (✉)
University of Teacher Education, Bern, Switzerland
e-mail: angelika.pahl@phbern.ch

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_5

In Swiss kindergarten and lower primary-school classes, about 95% of teachers are women. In the upper levels of primary schools, the proportion of women is 83% (Bundesamt für Statistik 2020). Gender differences in the field of science are known from studies of secondary school students (e.g. ROSE). These studies have found that girls prefer biology as a subject, whereas boys prefer physics and chemistry (Elster 2007). In the course of schooling, female pupils in particular gradually show less interest in chemistry and physics (Merzyn 2008), which is also reflected in their career choices. Only 21% of Swiss physics students are female (Dubach et al. 2017). The motives for choosing a profession depend on one's interests and abilities, but also one's personality. People who pursue a profession in physics are mostly 'realistic' and 'investigative' types, while those who become teachers are more likely to be 'social' types (Holland 1997). If students choose teacher training for kindergarten and primary school in Switzerland, they cannot leave out science, or specifically physics. Actually, they should be qualified to teach all subjects. Therefore, it is important in teacher training to ensure that personal dislikes (of physics, for example) do not impact professional attitudes.

Some studies have indicated that teacher training is capable of changing attitudes. Thus, offering qualitatively good science courses as part of teacher training can lead students to appropriate convictions, positive attitudes and improved self-confidence with regard to teaching science (Kazempour 2014). Therefore, it is crucial that the courses are geared to the specific needs of the students and offer them the opportunity to conduct science experiments themselves (Haase 2009). In-service training results show that the conscious inclusion of self-reflection, coupled with the idea that science teaching can be easily implemented in a positive manner, affects teachers' attitudes toward science teaching (van Aalderen-Smeets and Walma van der Molen 2015). Yilmaz-Tuzun (2008) emphasised that the convictions of student teachers when they enter a study programme must be considered during the training and, if necessary, consciously changed, as their convictions can influence their development of new knowledge and skills. If contrary or negative beliefs are not addressed and changed through university education, their later teaching practice may be determined more by their own personal beliefs than by the know-how taught at university (Yilmaz-Tuzun 2008; Hollingworth 1989).

At the University of Teacher Education Bern, trainee teachers complete a bachelor's degree programme to obtain teaching qualifications for kindergarten and lower primary school (so-called cycle 1) or grades 3–6 of primary school (cycle 2). In Switzerland, the subject in which science is taught is called 'nature–human–society' (NMG, or 'Natur–Mensch–Gesellschaft' in German). This subject integrates disciplines such as biology, physics, technology, geography, history, economics, religious studies and social sciences. During teacher training, trainees attend three NMG modules with 5 ECTS points each: In module NMG-1, students are introduced to an interdisciplinary understanding of the subject and constructivist learning theory. In module NMG-2, students learn how to plan, conduct and evaluate lessons. In module NMG-3, they receive specialisation in selected disciplines of NMG and long-term curriculum planning. Since the modules are conceived as multidisciplinary, there is not enough time to deepen the students' knowledge of all disciplines covered.

Therefore, teacher training in Bern focuses on NMG modules for the acquisition of pedagogical content knowledge (PCK) (Kalcsics et al. 2021). According to Shulman (1986, 1987), PCK is the knowledge that teachers need in order to transform content knowledge for student learning. It includes knowledge about learners and an understanding of 'the most regularly taught topics in one's subject area' and 'ways of representing and formulating the subject [...] to make it comprehensible' for learners (Shulman 1987) (p. 9). Therefore, it is a 'special amalgam of content and pedagogy' (Shulman 1987) (p. 8). Magnusson et al. (1999) specified a PCK component model for science teaching. It provides an orientation to teaching science, shaping knowledge of science curricula, knowledge of students' understanding of science, knowledge of science-specific instructional strategies and knowledge of assessment of science literacy.

1.1 Physics Topics and Competencies According to the Swiss Curriculum

The following is a list of selected competencies from the Swiss curriculum 21 that refer (more or less) to physics topics (Erziehungsdirektion des Kanton Berns 2016):

- Movement and forces: In cycle 1, children should explore how objects (e.g. balls, toy cars, swings) can be set in motion in different ways (e.g. rolling, throwing); they should learn how to describe the effects of forces in everyday life (e.g. moving by lifting, dropping, pushing) and discover the phenomena of balance and imbalance (e.g. with building blocks, seesaws). In cycle 2, pupils should explore the leverage effect and learn to explain how levers work (e.g. lifting something heavy). Pupils should become familiar with time and distance measurements, learn to describe speed and speed differences and recognise the interplay of size and direction of forces (e.g. trajectory of a thrown ball).
- Energy and energy transformation: In cycle 1, children should perceive and describe energy transformation processes or transmission (wound spring powering toy car, water becoming warm/cooling down). They should learn where energy occurs and how energy is important for everyday life (e.g. without electrical energy, certain devices do not work). Pupils in the second cycle should learn to name different forms of energy (e.g. kinetic, thermal, chemical energy) and assign them to specific energy sources (e.g. wind, water, sun, food). They should learn how energy can be stored and provided (e.g. battery, water reservoir) and recognise energy transformers (e.g. generator).
- Substance properties and processing: Children in kindergarten and grades 1–2 should observe and describe the characteristics of substances and objects in their daily life (e.g. heavy, elastic, floating, liquid, and cold). They should learn how materials can be processed (e.g. melting wax, grinding nuts). In grades 3–6, pupils should learn more about the properties of substances (e.g. conductivity, state of aggregation, ductility, hardness, and density) through laboratory work.

They should recover substances from the soil or water by separation processes (e.g. filtration, evaporation).

- Electricity and technical applications: In cycle 1, children should be able to insert batteries (e.g. in a flashlight) and learn to build a simple circuit and name all the components. In cycle 2, they should learn to construct branched electrical circuits (series and parallel connections) and to represent and read circuits schematically. Pupils should be able to describe electric currents as small moving particles and to make the analogy to flowing water. They should determine the electrical conductivity of different objects experimentally.
- Magnetism and technical applications: In cycle 1, children should explore different magnets and magnetic toys and describe their force effect (push-off, put on, nothing happens). They should learn that equal poles repel each other and unequal poles attract each other. In cycle 2, pupils should study the magnetic effect in more detail (e.g. checking the load capacity of magnetic hooks) and build electromagnets with simple materials under supervision.
- Acoustic: Children in cycle 1 should explore sound sources (e.g. traffic noises, bird chirps, silence, singing) and learn about protective measures for loud noises (e.g. headphones). Pupils in cycle 2 should be able to explore and describe the relationship between vibrations and sounds. They should be familiar with different acoustic phenomena and laws (e.g. sound propagation, echoing, sound amplification, and sound insulation).
- Optics: In cycle 1, children should learn to distinguish different light sources and investigate light and shadow phenomena. Pupils in grades 3–6 should be able to use a magnifying glass and binoculars. They should explore and describe different optical phenomena (e.g. play gel images, refraction, prisms) and eventually become familiar with the light beam model.
- Weather and weather conditions: In cycle 1, children should talk about their experiences with the weather, recognise the effects of different types of weather and learn to observe and depict simple weather phenomena (e.g. clouds, wind, and rain). In cycle 2, pupils should learn to conduct measurements and experiments on weather elements (e.g. temperature, precipitation, wind, air pressure). They should be able to diagram their weather observations and read weather forecasts.
- Earth and universe: Children in cycle 1 should be able to describe observable phenomena in the day and night sky (e.g. sun, moon, stars). Pupils in grades 3–6 should learn more about special phenomena and properties of celestial bodies (e.g. phases of the moon).

1.2 Research Aims

At the beginning of teacher training, students are not expected to have PCK or know the content of the Swiss curriculum 21 for kindergarten and primary school that has been in force since the 2018–2019 academic year (Erziehungsdirektion des Kanton Berns 2016). However, they all bring the experience of their early school days and have associations with physics and its concepts. From previous studies with a subsample of this target group, namely female students studying cycle 1 at the University of Teacher Education Bern, it is known that in the field of physics, the science knowledge of student teachers influences the perceived capability of and emotional engagement in physical-technical contents (Tschiesner and Pahl 2019).

This study explores the ideas of trainee teachers regarding suitable physics topics for kindergarten and primary school and topics within the spectrum of NMG that they prefer to teach. Furthermore, the status quo of beginners in teacher training for kindergarten and primary school should be recorded to find out how affection, experience and perceived capability regarding NMG content areas and particularly physics, are expressed. In contrast to previous studies, the sample was expanded to include cycle 2 as a target and differences in students' assessments regarding gender and teacher training focus were investigated.

2 Methods

For the descriptive and analytical research aims, a cross-sectional study was conducted at the University of Teacher Education Bern. All beginners in the bachelor teacher training programme for kindergarten and primary school were included in the sample. The survey took place one week before the first semester started. Via mail, the students were asked to participate anonymously in an online survey in preparation for the first NMG lecture at the university.

2.1 Data Collection

The online survey was carried out with ILIAS tools and collected qualitative and quantitative data. In the first part of the survey, students were asked open questions to elicit information about their conceptions concerning the teaching of physics within the NMG subject area. The respondents were asked to write down which physics topics they would teach at their target level (kindergarten and/or primary school) if they had to teach physics immediately. The same question was also asked regarding other content areas of NMG, but these data were not considered for analysis in this paper.

In the second part, quantitative data were collected through the NMG questionnaire (Pahl et al. 2019). This questionnaire captured trainee teachers' affection, experience and perceived capability in relation to seven content areas of NMG (social/ethical, cultural/religious, historical/political, geographical, economic, physical/technical and biological). Students had to assess items on a five-level Likert scale (total of 63 items). The nine items of each content area were organized according to three scales: affection, experience and perceived capability. The affection subscale included items evaluating the interest in and the emotional affinity for a specific content area. The experience subscale captured experiences gained in formal and informal learning settings and, in turn, familiarity with the different content areas. The perceived capability subscale referred to academic self-concept and self-efficacy beliefs related to mastering specific content areas of NMG teaching. In the standardisation sample, the reliability of the three subscales of all content areas ranged from acceptable to very good (Pahl et al. 2019). The focus of this investigation was on the physical/technical scales. The results of other content areas could be used as reference scores to evaluate the students' assessments of physics.

In the third part of the survey, a list of 12 teaching topics was presented to the trainee teachers, who were asked to choose their three favourite and least favourite topics within the social and natural sciences spectrum of the NMG subject area (Müller and Adamina 2008).

Finally, the survey recorded the socio-demographic characteristics of the trainee teachers, such as age, gender, chosen major field of study and previous education.

2.2 Data Analysis

Qualitative data regarding students' conception of suitable physics teaching content were evaluated by content analysis and transferred into thematic categories. The categories were first formed inductively (based on the concepts named by the students) and then deductively (based on the physics content of the Swiss curriculum). The evaluation was carried out as a cross-case analysis so that numerical values indicated whether a participant had paid attention to the thematic categories. With all quantitative data collected in the survey, descriptive and inferential statistics were carried out through SPSS and R.

3 Results

3.1 Sample

Of the 291 first-semester students enrolled in the kindergarten and primary-school teacher programme at the University of Teacher Education Bern in an academic year, 269 students participated in the survey. The sample comprised 213 women (79.2%) and 56 men (20.8%). The average age of subjects was 22.52 years ($SD = 4.74$). Among the students, 86 (32%) were enrolled in cycle 1, teaching in kindergarten up to grade 2 of primary school and 183 (68%) were enrolled in cycle 2, teaching in primary-school grades 3 to 6. In all, 155 subjects (57.6%) had a high school diploma and 114 (42.4%) did not. In their previous education, 36 (13.4%) students chose to focus on natural science and 233 (86.6%) did not.

Table 1 Results of NMG questionnaire

NMG content areas	Affection *M (SD)* Skewness, Kurtosis	Experience *M (SD)* Skewness, Kurtosis	Perceived capability *M (SD)* Skewness, Kurtosis
Social-ethical	4.15 (0.76), −0.59, −0.50	3.37 (0.74), −0.23, 0.05	3.60 (0.70), −0.23, 0.85
Cultural-religious	3.96 (0.81), −0.51, −0.13	3.22 (0.88), 0.23, −0.31	3.64 (0.74), 0.05, −0.51
Historical-political	3.80 (0.96), −0.47, −0.54	3.42 (0.88), −0.28, −0.36	3.55 (0.86), −0.35, 0.03
Geographical	4.05 (0.84), −0.70, 0.11	3.56 (0.79), −0.19, −0.15	3.77 (0.73), −0.31, 0.06
Economic	3.29 (0.96), 0.07, −0.57	2.93 (0.82), 0.09, −0.03	3.26 (0.90), 0.03, −0.14
Physical-technical	3.50 (1.03), −0.32, −0.65	3.01 (0.89), 0.02, −0.22	3.24 (0.88), −0.18, −0.10
Biological	4.53 (0.63), −1.41, 1.90	4.13 (0.73), −0.76, 0.63	4.13 (0.69), −0.54, 0.49

3.2 Affection, Experience and Perceived Capability Regarding Different NMG Content

The NMG questionnaire results (see Table 1) produced a Cronbach's alpha range from 0.88 to 0.93 for affection scales, 0.61–0.78 for experience scales and 0.75–0.89 for perceived capability scales. The Skewness and Kurtosis values of data sets are shown in Table 1.

As Table 1 shows, on the affection scale, subjects had the highest scores (min = 1, max = 5) on the biological and social-ethical scales. The lowest scores were seen on the economics and physical-technical scales. On the experience scale, the highest scores were seen on the biological and geographical scales. The lowest scores were observed on the economics and physical-technical scales. On the perceived capability scale, subjects had the highest scores on the biological and geographical scales. The lowest scores were found on the physical-technical and economics scales.

3.3 Physics Scores: Differences Between Groups (Gender and Teacher Training Focus)

The following analysis focuses on the physical-technical scales of the NMG questionnaire. Sample group differences regarding gender and teacher training focus (cycle 1 or 2) were calculated. When gender is taken into account, it is noted that male subjects had significantly higher scores than female subjects in all physical-technical subscales of the NMG questionnaire (affection, experience and perceived capability):

- Affection: female: $M = 3.42$ ($SD = 1.02$); male: $M = 3.81$ ($SD = 1.01$); $T = -2.538$, $p < 0.05$, $d = -0.38$
- Experience: female $M = 2.92$ ($SD = 0.86$); male $M = 3.34$ ($SD = 0.93$); $T = -3.158$, $p < 0.05$, $d = -0.47$
- Perceived capability: female: $M = 3.13$ ($SD = 0.85$); male: $M = 3.65$ ($SD = 0.88$); $T = -4.024$, $p < 0.001$, $d = -0.39$

No significant differences between trainee teachers in cycles 1 and 2 were found for the physical-technical affection scale (cycle 1: $M = 3.38$ ($SD = 1.00$); cycle 2: $M = 3.56$ ($SD = 1.04$); $T = -1.358$, n.s.) and physical-technical experience scale (cycle 1: $M = 2.86$ ($SD = 0.84$); cycle 2: $M = 3.08$ ($SD = 0.91$); $T = -1.831$, n.s.). On the other hand, students enrolled in cycle 2 ($M = 0.32$, $SD = 0.88$) had significantly higher scores on the physical-technical perceived capability scale than those in cycle 1 ($M = 3.05$, $SD = 0.87$; $T = -2.346$, $p < 0.05$, $d = -0.31$).

When both gender and teacher training focus variables were included in the calculation and compared, the parameters were as follows:

- Affection: female cycle 1: $M = 3.34$ ($SD = 0.99$); female cycle 2: $M = 3.47$ ($SD = 1.03$); male cycle 2: $M = 3.78$ ($SD = 1.03$).
  One-way ANOVA: $F = 3.005$, $df = 2$, n.s.
- Experience: female cycle 1: $M = 2.82$ ($SD = 1.03$); female cycle 2: $M = 2.99$ ($SD = 0.88$); male cycle 2: $M = 3.31$ ($SD = 0.96$).
  One-way ANOVA: $F = 4.820$, $df = 2$, $p < 0.01$
- Perceived capability: female cycle 1: $M = 3.01$ ($SD = 0.84$); female cycle 2: $M = 3.20$ ($SD = 0.85$); male cycle 2: $M = 3.64$ ($SD = 0.88$).
  One-way ANOVA: $F = 8.496$, $df = 2$, $p < 0.001$

Male subjects with a focus on cycle 1 had to be excluded from analysis because the sample size of this group was too small for comparative analysis ($n = 5$). With the three remaining groups (female cycle 1 ($n = 81$), female cycle 2 ($n = 132$) and male cycle 2 ($n = 51$)) one-way ANOVA was conducted to find out if there were any group differences between them.

One-way ANOVA showed no significant differences in affection scale, but significant group differences regarding the experience and perceived capability scales were found. Posthoc tests (Bonferroni) showed that male students in cycle 2 had significantly higher scores on the experience scale than female students in cycle 1 (mean diff. = -0.488, $p < 0.01$). Female students in cycle 1 compared to cycle 2 and female students in cycle 2 compared to male students in cycle 1 did not differ significantly. Looking at the perceived capability scale, posthoc tests showed that female subjects did not differ from the others, but female students in cycle 2 differed significantly from male students in cycle 2 (mean diff. = -0.436, $p < 0.01$) and female students in cycle 1 significantly differed from male students in cycle 2 (mean diff. = -0.625, $p < 0.001$). In conclusion, the analysis shows that the sample was not homogeneous.

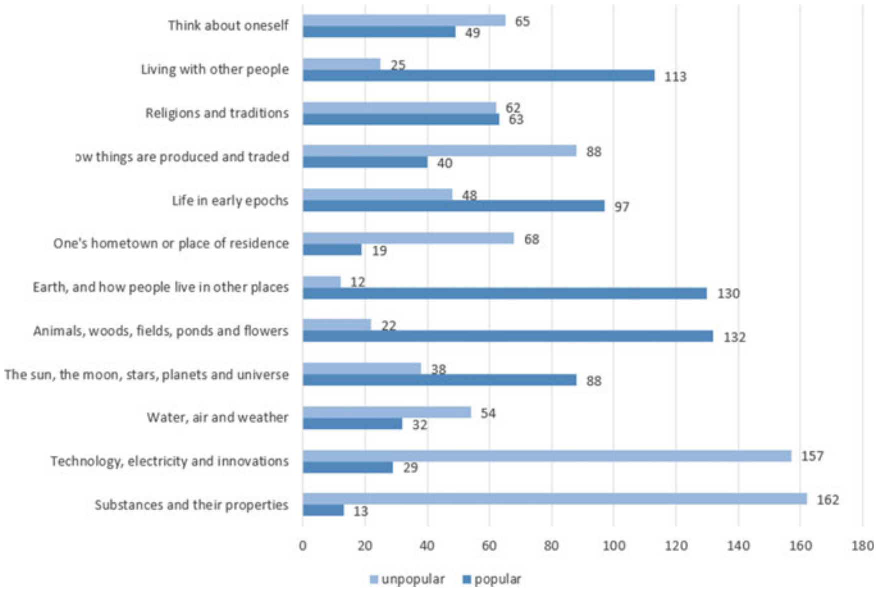


Fig. 1 Most and least favourite content to teach from NMG (frequency)

3.4 Favourite and Least Favourite Content to Teach

Figure 1 shows the teaching content chosen by students when asked to indicate their three most and least favourite to teach from a list of 12 topics from the NMG subject area.

Within the natural and social science content areas, 'substances and their properties' and 'technology, electricity and innovations' were the most unpopular teaching content for trainee teachers. Accordingly, these topics were mentioned by very few students as one of their three favourites. The three most popular topics to teach were 'animals, woods, fields, ponds and flowers'; 'Earth and how people live in other places'; and 'living with other people'. These, in turn, were also the three topics least likely to be rejected by students.

3.5 Students' Conceptions of Physic Topics

In Table 2, opinions about suitable physic topics for kindergarten and/or primary school are thematically categorised according to frequently mentioned concepts by the trainee teachers (inductive categories). The most frequently mentioned concept was doing experiments, which, strictly speaking, does not represent a physics topic but rather a methodological approach to the natural sciences. Sometimes, the term 'doing experiments' was not linked to any physics content, indicating that some

Table 2 Inductive categories formed according to students' answers

Number of mentions	Category	Anchor Example
70	Doing experiments	Conducting simple science experiments with pupils
68	Electricity	Building a simple circuit; what needs electricity?
49	Gravity	Gravity; how fast and why do objects fall to the ground?
40	Energy	How energy is generated and/or transformed
39	Light and optics	Light; magnifier; colour spectrum; light refraction
33	Magnetism	Magnets; attraction and repulsion
27	Not specified	Simple physical laws; simple science experiments
26	Planet and universe	Sun, moon, stars; solar system
26	Substance properties	Density, temperature; getting to know different materials
25	I do not know	I have no idea; no answer
24	Mechanics	Simple basic laws of mechanics
23	Physics in daily life	Illustrating the physics of everyday life
20	Forces	Effects of forces; which forces act where and why?
20	Water	Experiments with water; water cycle
19	Swim, fly, hover	Investigating what floats, what sinks
17	Movement, velocity	Speed of different vehicles; acceleration
16	States of aggregation	States of aggregation
16	Thermodynamics	Thermodynamics; heat and cold
10	Not physics	Chemistry, biology; chemical reactions
9	Acoustics	Acoustic phenomena; sound waves
7	Weather	Weather phenomena; storms, rain
2	Physics is too complex	I think physics is too difficult for children

students could not distinguish between activity and content. Some students also only named an object of learning (e.g. water) but did not specify which physics principles were to be learned. In addition, other answers were so general that no specific content became clear; for example, the statement 'simple physical laws'. Therefore, the category 'not specified' was introduced.

Furthermore, false answers were found (categorised as 'not physics'), showing that it was difficult for individual students to distinguish between biology, chemistry and physics topics. In this context, 'chemistry and biology' was a particularly inappropriate answer to the question of physics topics. Answers that addressed interdisciplinary topics were categorised on their own, for example, 'weather'. As Table

2 shows, the topics of electricity and gravity were most prominently represented in trainee teachers' conception of physics in kindergarten and primary school.

Overall, the level of abstraction in the answers was quite different when the students were describing physics topics. Some students used superordinate terms (e.g. physical properties of substances) and others used subordinate terms (e.g. states of aggregation). Moreover, some students simply mentioned single concepts (e.g. gravity), while others gave specific examples (e.g. investigating how fast objects fall to the ground). Regarding the responses to single words, it was not possible to assess whether the students were capable of finding in this context a level of difficulty that was suitable for children.

Finally, the results show that some students could not identify any physics topic or indicated that physics, in their opinion, would be too complex for children in kindergarten and primary school. For the categories 'not physics', 'I do not know' and 'not specified', no significant gender differences or differences regarding the training focus were found.

In the second step of the analysis, student answers regarding suitable physics content were assigned to the nine physics topics of the Swiss curriculum 21. From these topics, properties and processing of substances were categorised 75 times (28.4%), electricity 68 times (25.8%), movement and forces 52 times (19.3%), energy and energy transformation 40 times (14.9%), optics 39 times (14.5%), magnetism 33 times (12.3%), Earth and universe 26 times (9.7%), acoustics nine times (3.3%) and weather seven times (2.6%). Summing up the categories mentioned by each student, the average score for the sample was 1.44 named physics topics ($SD = 1.25$, min = 0, max = 6). As for the distribution of the number of mentioned topics, 66 students (25.0%) did not name any from curriculum 21 and 89 (33.7%) mentioned one topic. A skewness of 0.838 indicates an accumulation of scores on the left side of the distribution (see Fig. 2). Less than half the students (109; 41.4%) could name two or more physics topics. High numbers of named physics topics correlated significantly with high scores of physical-technical affection scale ($r = 0.16$, $p < 0.01$), experience

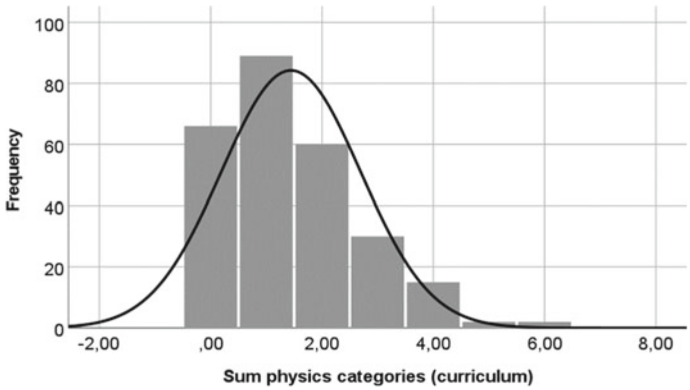


Fig. 2 Distribution of frequencies regarding naming of physic topics

scale ($r = 0.19$, $p < 0.01$) and perceived capability scale ($r = 0.16$, $p < 0.01$) of the NMG questionnaire.

4 Conclusion

This study aimed to determine what trainee teachers, before the start of training, think of teaching physics in kindergarten and primary school.

Similar to previous studies, distributions of most NMG scores indicated a tendency towards high scores. They showed that trainee teachers preferred NMG content from the social-ethical, geographical, historical and biological areas and were more confident in teaching topics in these areas. In contrast, the effect of high scores disappears for the physical-technical and economic areas and the distribution becomes more like a Gaussian distribution. This type of distribution indicates notably more variety, thus more significant differences in trainee teachers' attitudes regarding the physical-technical and economic areas of NMG. Furthermore, the finding that trainee teachers disliked teaching topics that deal with, for example, technology, electricity or innovations indicates that physics and technology, in general, are not popular topics.

In the literature, the gender effect regarding students' attitudes towards physics is well known. This study confirms that male trainee teachers are more confident than their female counterparts in their ability to teach physics and technical content and express more positive emotions, such as having an interest in physics and technology. Effect sizes by Cohen's d are considered small to medium.

In this study, the teacher training focus of students at the University of Teacher Education Bern was examined for the first time. Knowledge regarding physics topics by students who attend teacher training for cycle 2 should be more sophisticated compared to cycle 1 because the content is more complex, so it was assumed that the characteristics of trainee teachers in the groups would differ. In general, the results did not show significant differences. Only male trainee teachers studying cycle 2 had significantly higher scores regarding their attitude towards and capacity to teach physics and technical content than female trainee teachers in cycles 1 and 2. Male students in cycle 1 were not considered in this analysis because they were underrepresented in the sample; therefore, results regarding this specific sample group are missing. Another limitation of this study is the poor reliability of the experience scale. These parameters indicate possible measurement errors, which require a careful interpretation of results that include the experience scale.

As previously discussed, the qualitative part of this investigation generated evidence about what trainee teachers know and think about regarding physics topics in kindergarten and primary school. The three most popular physics topics indicated by the sample are properties and processing of substances, electricity as well as movement and forces. It is disquieting that almost a quarter of the sample gave no answer, incorrect answers or such nonspecific answers that they could not name more than tautological concepts such as physical laws. Only one participant was able to indicate six out of nine curriculum topics. Slightly more than half of the students named only one topic. However, in addition to the quantitative view of the answers, the quality must also be considered. As previously mentioned, the answers were extremely heterogeneous. For example, the term ‘Newton’s laws’ was given as an abstract concept from the curriculum category ‘movement and forces’, while the statement ‘observe how balls roll on a track (depending on mass, starting height of the balls)’ shows a concrete example that would be suitable for a primary-school physics lesson. However, the degree of abstraction could not be differentiated in the evaluation because it was not clear how detailed the student’s answer should be; thus, no meaningful results were possible in this respect. However, it becomes clear that some students think in terms other than those defined by the curriculum and there is often a lack of hierarchical structure in the terminology. Many students associate physics with experimentation; science experiments generally have a positive connotation among pupils. However, it is also important for teachers to know why they are conducting science experiments with children; they should aim to provide entertaining hands-on science activities, as well as clarify certain physical principles to change or develop the children’s physical concepts.

Just as teachers should consider children’s pre-concepts, this study implies that in teacher training, more attention should be given to students’ conceptions. It is necessary to engage the trainee teachers’ imaginations and develop them to reach an appropriate, structured picture of physics and its phenomena in everyday life. Even if there is not enough time in teacher training to thematise and concretise every fundamental concept, the aim should be to provide a framework or a structured overview of central concepts of physics that will give them an orientation in their later teaching practice.

If one looks at the physics content of the Swiss curriculum, it does not give the impression of being too theoretical or complex, which is how the subject is often criticized by secondary school students. If trainee teachers realise that physics in kindergarten and primary school is not inscrutable and incomprehensible, the self-concept to be able to teach this content would probably increase. In this respect, there is the possibility that trainee teachers’ professional attitude could develop positively in the unpopular field of physics.

References

Appleton K (2007) Elementary science teaching. In: Abell SK, Lederman NG (eds) Handbook of research on science education. Routledge, New York, pp 493–535. https://doi.org/10.4324/9780203824696

Bundesamt für Statistik (2020) Frauenanteil bei den Lehrkräften nach Bildungsstufe und Schuljahr (öffentliche Schulen). BFS, Neuchâtel. https://www.bfs.admin.ch/bfs/de/home/statistiken/wirtschaftliche-soziale-situation-bevoelkerung/gleichstellung-frau-mann/bildung/lehrkraefte.assetdetail.14307193.html

Dubach P, Legler V, Morge M, Stutz H (2017) Frauen und Männer an Schweizer Hochschulen: Indikatoren zur Chancengleichheit in Studium und wissenschaftlicher Laufbahn. BASS, Bern. https://www.buerobass.ch/fileadmin/Files/2017/CGHS_2017_Indikatorenbericht.pdf

Elster D (2007) In welchen Kontexten sind naturwissenschaftliche Inhalte für Jugendliche interessant? Ergebnisse der ROSE Erhebung in Deutschland und Österreich. Plus Lucies 3:2–8. https://www.univie.ac.at/pluslucis/PlusLucis/073/s2_8.pdf

Erziehungsdirektion des Kanton Berns (2016) Lehrplan 21: Fachbereichslehrplan Natur, Mensch, Gesellschaft. Gassmann Print, Biel/Bienne

Haase RP (2009) Elementary teachers' attitudes toward science and the teaching of science and technology. Electronic Theses and Dissertations, University of Windsor. https://scholar.uwindsor.ca/etd/245

Hacieminoglu E (2016) Elementary school students' attitude toward science and related variables. Int J Environ Sci Educ 11(2):35–52. https://doi.org/10.12973/ijese.2016.288a

Holland JL (1997) Making vocational choices. In: A theory of vocational personalities and work environments (3rd ed). Psychological Assesment Ressources, Odessa

Hollingworth S (1989) Prior beliefs and cognitive change in learning to teach. Am Educ Res J 26:160–189. https://doi.org/10.3102/00028312026002160

Kalcsics K, Conrad SJ (2021) Natur, Mensch, Gesellschaft (NMG) im Studiengang Vorschulstufe und Primarstufe an der PHBern. In: Breitenberger P, Mathis C, Tempelmann S (eds) Natur, MensCH, Gesellschaft (NMG) – Beiträge zur sachunterrichtsdidaktischen Aus- und Weiterbildung von Lehrpersonen in der Schweiz. Schneider, Baltmannsweiler, pp 17–28

Kazempour M (2014) I can't teach science! A case study of an elementary pre-service teachers' intersection of science experiences, beliefs, attitude, and self-efficacy. Int J Environ Sci Educ 9:77–96. https://doi.org/10.12973/ijese.2014.204a

Kleickmann T (2015) Professionelle Kompetenz von Primarschullehrkräften im Bereich des naturwissenschaftlichen Sachunterrichts. Zeitschrift Grundschulforschung 8(1):7–22

Magnusson S, Krajcik J, Borko H (1999) Nature, sources, and development of pedagogical content knowledge for science teaching. In: Gess-Newsome J, Lederman NG (eds) Examining pedagogical content knowledge: the construct and its implications for science education. Kluwer Academic Publishers, Dordrecht, pp 95–132. https://doi.org/10.1007/0-306-47217-1_4

Merzyn G (2008) Naturwissenschaften, Mathematik, Technik – immer unbeliebter? Die Konkurrenz von Schulfächern und das Interesse der Jugend im Spiegel vielfältiger Untersuchungen. Schneider, Baltmannsweiler

Müller H, Adamina M (2008) Der Zugang über Experimente und Erprobungen zum eigenen Lehren und Lernen. Broschüre aus dem Grundlagenband Lernwelten Natur-Mensch-Mitwelt. Schulverlag, Bern

Pahl A, Tschiesner R, Adamina M (2019) The 'nature-human-society'-questionnaire for kindergarten and primary school trainee teachers: psychometric properties and validation. In: Gómez Chova I, López A, Candel Torres I (eds) ICERI2019 Proceedings vol 12. IATED Academy, Seville, pp 3196–3205. https://doi.org/10.21125/iceri.2019.0812

Pahl A, Tschiesner R (2022) What influences attitudes and confidence in teaching physics and technology topics? An investigation in kindergarten and primary-school trainee teachers. Sustainability 14(1):87. https://doi.org/10.3390/su14010087

Pendergast E, Lieberman-Betz RG, Vail CO (2017) Attitudes and beliefs of prekindergarten teachers toward teaching science to young children. Early Childhood Educ J 45(1):43–52. https://doi.org/10.1007/s10643-015-0761-y

Shulman L (1986) Those who understand: knowledge growth in teaching. Educ Res 15(2):4–11. https://doi.org/10.3102/0013189X015002004

Shulman L (1987) Knowledge and teaching: foundations of new reform. Harv Educ Rev 57(1):1–22. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Tschiesner R, Pahl A (2019) Trainee teachers' preferences in the subject 'nature-human-society': the role of knowledge. In: Gómez Chova I, López A, Candel Torres I (eds) ICERI2019 Proceedings vol 12. IATED Academy, Seville, pp 3167–3176. https://doi.org/10.21125/iceri.2019.0806 van Aalderen-Smeets S, Walma van der Molen J (2015) Improving primary teachers' attitudes toward science by attitude-focused professional development. J Res Sci Teaching 52(5):710–734. https://doi.org/10.1002/tea.21218

Yilmaz-Tuzun O (2008) Preservice elementary teachers' beliefs about science teaching. J Sci Teacher Educ 19:183–204. https://doi.org/10.1007/s10972-007-9084-1

A Teacher Training Course on Using Digital Media for Acquisition, Visualization and 3D Printing of Complex Data and for Fostering Pupils' Experimental Skills

Lars-Jochen Thoms, Christoph Hoyer, and Raimund Girwidz

Abstract In a newly designed course on special questions about multimedia in physics teaching and learning, multicoding, multiple and multimodal (haptovisual) representations of complex measurement data are created (for example, by 3D printing). In addition, the pre-service teachers in this seminar design interactive learning and working materials for pupils. The focus is on selecting, providing and using different task formats and visualizations in a way that is appropriate for the target group. The results of the accompanying pilot study show effective knowledge acquisition, especially in TPACK. Furthermore, the participants were able to implement the acquired learning content in the design of pupil-oriented, inquiry-based learning environments.

1 Introduction

Experiments play a central role in physics teaching. Set-up, preparation and optimal execution are important topics in studies and the focus of various courses. If the set-up of an experiment is too complex, dangerous, costly, or time-consuming, if the experimental material is not available, or if the conduction poses particular dangers, experimentation in the distance laboratory is an alternative way to teach experimental skills and competencies (Thoms and Girwidz 2015). The importance of remote learning for the future is reflected in the large number of highly funded past and present European research projects to develop and implement remote-controlled experiments via the Internet (Auer et al. 2018; Maletić et al. 2021; Persano Adorno and Pizzolato 2020). In particular, conducting an experiment via a computer or mobile device

L.-J. Thoms (✉) · C. Hoyer · R. Girwidz
Faculty of Physics, Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München, Germany
e-mail: lars.thoms@uni-konstanz.de

L.-J. Thoms
Department of Chemistry, University of Konstanz, Universitätsstr. 10, 78464 Konstanz, Germany

Thurgau University of Education, Unterer Schulweg 3, 8280 Kreuzlingen, Switzerland

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_6

opens up new possibilities for training experimental skills such as documenting measurement results (Hoyer and Girwidz 2020). Digital competencies regarding the selection of suitable representations and the visualization of measurement data can also be addressed (Hoyer and Girwidz 2018). Therefore, beyond the acquisition of experimental competencies, the appropriate use of digital media is also promoted. However, an unfavourably moderated use of digital media in the classroom carries the danger of a cognitive overload of the learners (Sweller 2010; Schnotz and Bannert 2003). Therefore, future teachers must be specially trained for this. The selection and provision of digital media for pupils requires sound technological pedagogical content knowledge (TPACK) (Koehler et al. 2013). Since only good teaching experience on the part of the teacher can ensure sustainable acceptance and appropriate use of digital media in the classroom (Mayer and Girwidz 2019), this professional teacher knowledge should already be imparted during university teacher training.

Despite the urgent need to incorporate digital competencies in teacher education (Carrillo and Flores 2020), research reveals a lack of ICT-oriented pre-service teacher training (Fernández-Batanero et al. 2020). In order to promote the integration of the use of digital media in teacher training, the *Joachim Herz Foundation* has founded the *Kolleg Didaktik: digital*, in which it supports teaching projects related to the use of digital media in science teaching.

This chapter describes a newly developed teaching concept to promote the use of digital media in physics education, which is primarily based on cognitive theories of multimedia learning (Mayer 2014). In addition to the benefits that can be achieved by taking into account the principles of multimedia learning, students are also made aware of possible negative influences on the learning process due to unfavourable implementations (Sweller 2010; Schnotz and Bannert 2003).

2 Methods

The teaching project, ‘Promoting experimental skills and training analysis of complex data with digital media’, was developed and has been carried out at the Chair of Physics Education at LMU Munich since the 2018 summer term. The project aims to provide prospective teachers with background knowledge on the targeted use of digital media in physics lessons. New content was integrated into existing seminars for learning and teaching physics, as well as for school-related experimentation. In addition, a compulsory elective in-depth course was offered in the winter term 2018/19 (2 h/week, 15 weeks, 3 ECTS credits, 90 h of total workload). The effectiveness of the implementations on attitudes towards and knowledge about the use of digital media in physics education was investigated through questionnaire surveys in a pre-post design. In addition, the students’ implementation of what they had learned in the learning materials produced was evaluated. The course ‘Teaching with digital media: multimedia and 3D printing in physics lessons’ has a modular structure. In this way, individual modules can easily be transferred to other courses. The modules of the course are briefly presented below.

2.1 Didactic Aspects of Multimedia Learning

When selecting suitable multimedia learning materials, not only technical aspects have to be considered. An unfavourably moderated use of digital media in the classroom harbours the risk of cognitive overload for the learners (Sweller 2010; Schnotz and Bannert 2003). Therefore, theories of multimedia learning are discussed (Mayer 2014). In addition, an online compendium with interactive examples on topics relevant to teaching is available for further illustration (Girwidz et al. 2018). Central to this is always the illustration of what has been learned using interactive examples on topics relevant to teaching. Participants thus not only learn about the theory behind multimedia physics teaching but also practical examples that can be beneficial in later teaching practice.

Figure 1 shows an animation with multiple representations of an accelerated motion as an example of multicoding. At the top left, a film-like representation of the motion of a steam locomotive is shown. At the top right, the motion is shown in a stroboscopic image of the colour-coded rear wheel. At the bottom left, we see in a diagram the position of the locomotive in metres plotted against time in seconds. In addition, the speed in m/s over time is plotted in a diagram at the bottom right. By linking the different representations, learners can deepen the new learning content and connect what they have learned with existing knowledge.

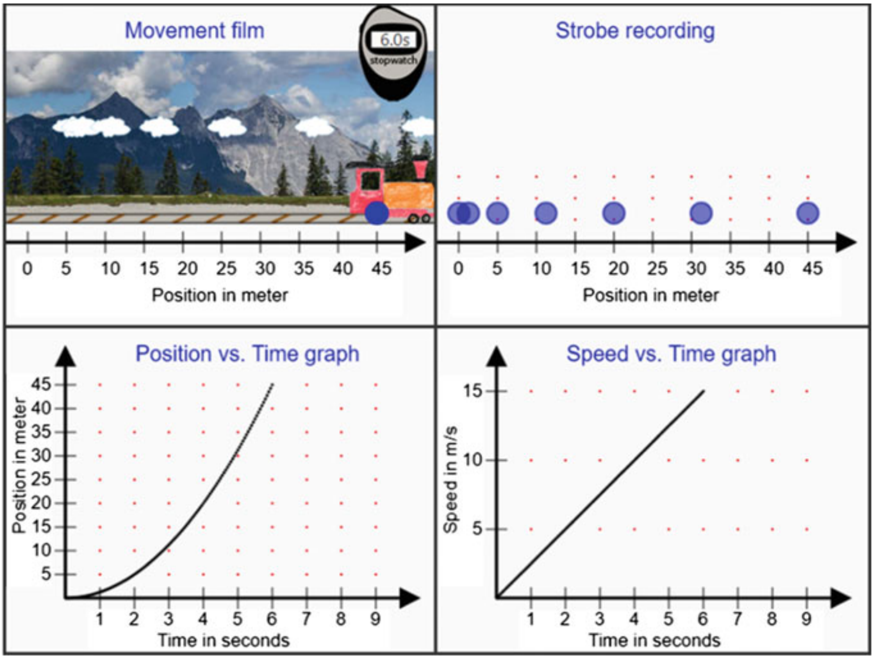


Fig. 1 Example of multiple representations of a constantly accelerated movement

Another example of multicoding is given in Fig. 2. The Boyle-Mariotte law is shown as a graph in a diagram, as an iconic model of the gas particles in a closed cylinder with variable volume and as a logical representation in the form of a mathematical formula. With the help of a 3D printer, three-dimensional models can be printed out and then be viewed by the learners and palpated with their hands at the same time. Figure 3 shows a multimodal representation of the *p*–*V*–*T* state curved surface of the ideal gas. An isotherm is drawn in the model. By rotating and tilting the model, the projections of the isotherm into the possible viewing plane become comprehensible for students.

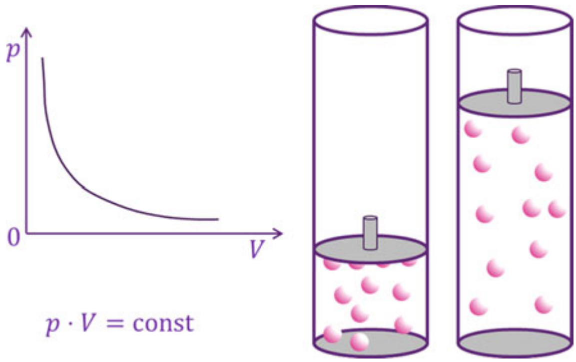


Fig. 2 Multicoding. Boyle-Mariotte law as graph, graphical representation and formula

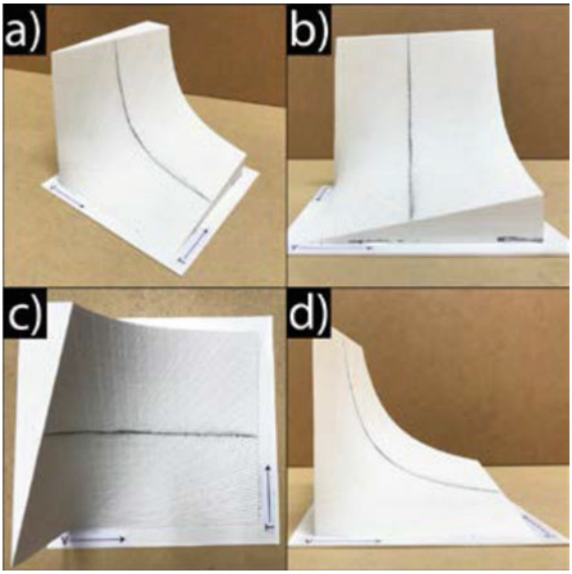


Fig. 3 Multimodality. 3D print of the *p*–*V*–*T* state curved surface of the ideal gas: **a** top view on the state surface, **b** *p*–*T* perspective, **c** *T*–*V* perspective, **d** *p*–*V* perspective (Hoyer et al. 2020)

2.2 Digital Media in Physics Lessons

The students learn about different types of multimedia applications and their advantages and disadvantages. Using an established evaluation scheme, animations, simulations and remote labs are analysed and categorized regarding motivational aspects, content and methodology (Altherr et al. 2003; Dębowska et al. 2013). This gives participants an overview of multimedia applications for physics teaching and learning. In addition, the assessment skills of the students are promoted.

2.3 Digital Data Acquisition in Real, Remote and Virtual Experiments

The possibilities of digital measurement acquisition in physics teaching have been immensely expanded by technological progress in recent years. Prospective teachers should have a broad knowledge of the available methods and the associated exciting and interesting new possibilities for conducting experiments, recording measured values and subsequent evaluation. Hence, students get to know different systems and use them in various experiments relevant to physics teaching. The course thus provides an overview of common methods for digital data acquisition. At the same time, the students have the opportunity to integrate these procedures into practical teaching scenarios and to try them out independently using common school experiments.

Digital data acquisition systems from the manufacturers of teaching aids are well established in physics teaching and are available in many schools. However, it is not possible to predict which system will be available at the future school of a prospective teacher. The different systems also have various advantages and disadvantages, depending on the specific purpose. Therefore, we attach great importance to the fact that our teacher candidates get to know different data acquisition systems during their studies and build up a teaching-related assessment competence regarding the use of digital data acquisition.

For tablets and smartphones, manufacturers of teaching aids also offer so-called smart sensors. These can be coupled directly with a mobile end device via Bluetooth. The sensors are set-up and the data is collected, processed and displayed directly on the mobile device. In addition, the data can also be transferred to other people or devices for further evaluation.

Smartphones and tablets have a variety of built-in sensors that can also be used for digital data acquisition. Depending on the model, some or all the following sensors can be used:

- GPS (indicates location)
- Accelerometer (measures acceleration)
- Gyroscope (measures rotation)
- Magnetometer (measures magnetic flux density)

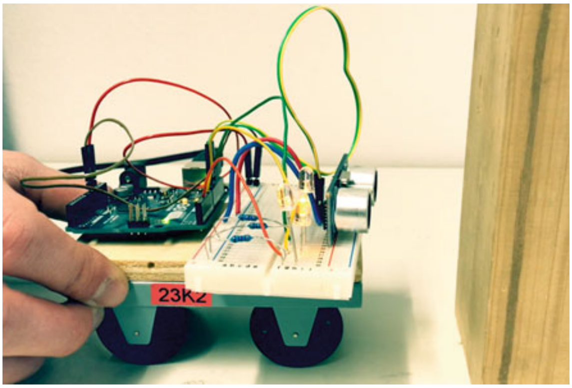


Fig. 4 Measuring distance with an Arduino and an ultra-sonic sensor

- Light sensor
- Proximity sensor (measures distance to an object)
- Barometer (measures air pressure)
- Pulse oximeter (measures oxygen saturation in blood and pulse rate).

The use of different **video analysis** apps, such as *Viana*, *Vernier Video Physics*, *VidAnalysis* and *Tracker*, is also tested in the seminar. For example, the students record the vertical throw of a ball from a moving car with Viana and evaluate the recording regarding different physical laws.

Microcontrollers and microcomputers such as **Arduinos and Raspberry Pis** can also be used to record measured values in physics lessons (Girwidz and Watzka 2018). Firstly, the acquisition costs are many times lower than for systems designed for a long service life and mechanical stability. Secondly, working with Arduino, Raspberry Pi and Co. also builds interdisciplinary skills. In the seminar, various experiments are carried out with the Arduino Uno, with the participants writing programme code themselves under guidance, planning and building circuits and then developing their own experimental instructions for later use in teaching practice (Fig. 4).

Remote and virtual laboratories allow student-friendly and independent experimentation, even in expensive or dangerous experiments (Thoms and Girwidz 2017). Students are given an overview of existing remote and virtual laboratories (Table 1, for exemplary remote labs, see Fig. 5, for a review of virtual and remote labs in education see (Heradio et al. 2016)). Furthermore, the implementation in teaching scenarios is discussed.

2.4 Two and Three-Dimensional Representations of Measured Values

If measured values are recorded digitally, they can be presented very easily, for example, via a beamer. However, modern technology offers many more possibilities

Table 1 Exemplary remote lab projects

Project	Country	Link
Remotely Controlled Laboratories—RCL	Germany	http://rcl-munich.informatik.unibw-muenchen.de/
Relle	Brazil	http://relle.ufsc.br/labs/
Rexlab	Brazil	https://rexlab.ufsc.br/
Ises	Czech Republic	http://ises.info/
Weblabdeusto	Spain	https://weblab.deusto.es/website/
GO-LAB	The Netherlands	https://www.golabz.eu/
FREI—Ferngesteuerte Reale Experimente über das Internet	Germany	https://frei.web.th-koeln.de/HTML/index.php
UNILabs	Spain	https://unilabs.dia.uned.es/
OpenSTEM Labs	United Kingdom	http://stem.open.ac.uk/study/openstem-labs
iLab Project @ MIT	USA	https://icampus.mit.edu/projects/ilabs/
Remote Farm	Germany	https://remote.physik.tu-berlin.de/

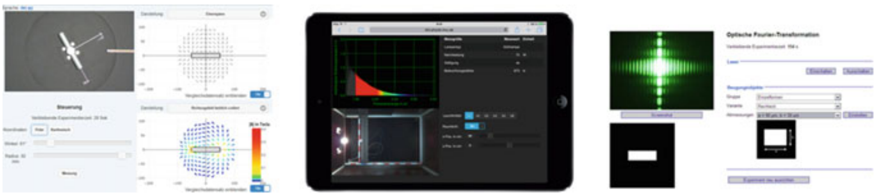


Fig. 5 Selected remote laboratories used in the course: magnetic field of a permanent magnet (left) (http://did.physik.lmu.de/sims/magneticfield/index_de.html), Spectrometric assessment of lamps (middle) (http://myrcl.net) and Optical Fourier transformation (right) (http://rcl-munich.informatik.unibw-muenchen.de/)

to present experimental results both two- and three-dimensionally. In the seminar, different visualizations of experimentally obtained data are discussed and tried out. Thereby, the use of remote labs has proven to be highly effective, as learners can initially concentrate fully on the characteristics of different forms of representation (Hoyer and Girwidz 2018) (Fig. 6). Thus, measured values are recorded, evaluated and visualized for standard experiments.

2.5 *3D Printing in Physics Teaching and Learning*

The ability to address multiple senses (multimodality) is one of the strengths of multimedia-based teaching. However, so far, multimodal applications have mostly been used to address content from acoustics (Girwidz et al. 2019a). 3D printing

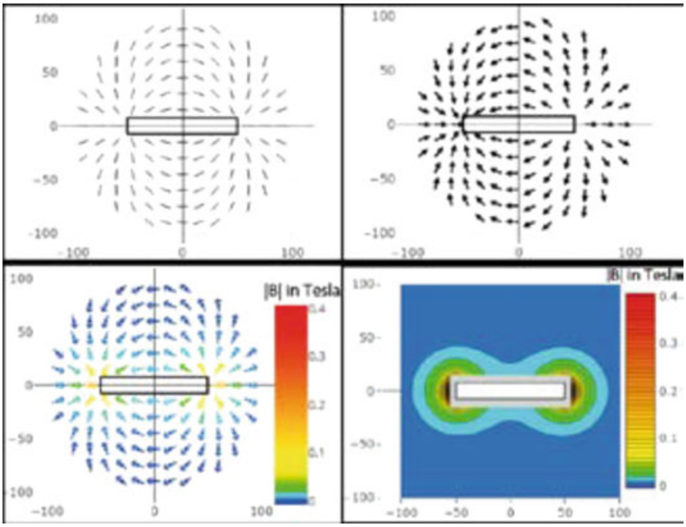


Fig. 6 Representations of the field of a magnet; each representation accentuates different information (Hoyer and Girwidz 2018)

offers an innovative way to produce haptovisual representations of complex relationships. Hence, basic knowledge of 3D printing is imparted. For example, students use *Tinkercad* to design a 3D model by themselves and then print it out. Participants also learn the basics of creating a 3D visualization of experimentally obtained data based on a student experiment they conducted themselves. As creating 3D printable models is usually complex and impractical for school practice, the (prospective) teachers need supportive assistance. Our approach was to provide web pages that can help with the creation of 3D printable models, both for functions and for measurements. For instance, the function plotter can be used to draw an interference pattern of two plane circular waves by using the formula

$$f(x, y) = \cos\left(\frac{2\pi}{10}\sqrt{(x-5)^2 + y^2}\right) + \cos\left(\frac{2\pi}{10}\sqrt{(x+5)^2 + y^2}\right) \quad (1)$$

and the interval for both x and y of $[-50;50]$. The function plotter will then generate a black and white image (Fig. 7) where the colouring of a pixel represents the maxima and minima, respectively, at the time shown. Students can easily import this image into 3D printing software (Fig. 8) and print it out (Fig. 9). 3D printing is particularly suitable for representations of potentials (Fig. 10), as the 3D printer applies individual layers one after the other, thereby automatically making equipotential lines visible (corresponding to the layer thickness).

We have also created a suitable website, especially for processing three-dimensional measurement data. The data is copied into a text field in a predefined format (Fig. 11) and again a black and white image is created in which the

Fig. 7 Visualization of the interference of two circular waves

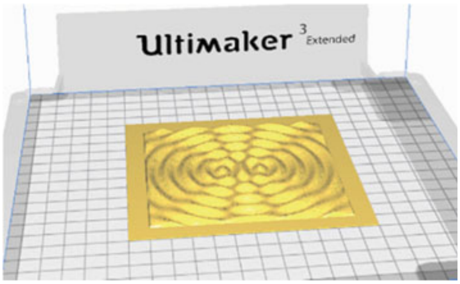


Fig. 8 The black and white image can easily be converted into a 3D model

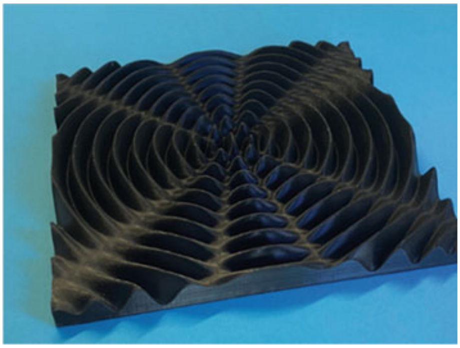


Fig. 9 3D print of the interference of two circular waves

z-component is coded in the pixel colour (Fig. 12), so that the measurement data can easily be printed out in three dimensions (Fig. 13).

Sometimes even direct recordings from a webcam can be usefully processed for 3D printing. For example, diffraction patterns can be recorded with a webcam (Fig. 14 left). The diffraction image can be used for 3D printing, whereby the brightness of

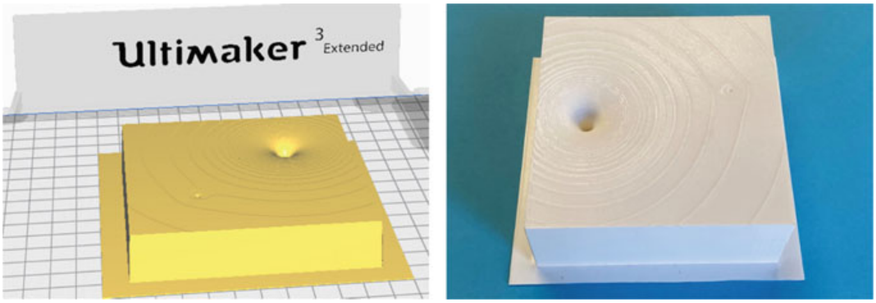


Fig. 10 3D model (left) and 3D print (right) of a two-dimensional slice of the gravitational potential of the earth and moon

Fig. 11 The function plotter accepts comma-separated values

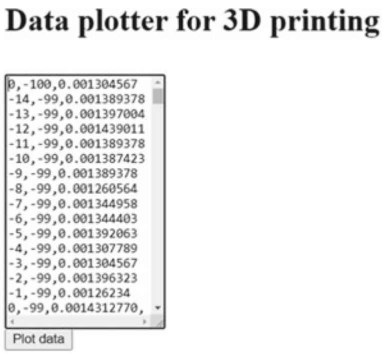


Fig. 12 Magnetic flux density around a bar magnet visualized as black and white image

the pixels is interpreted as a z-component in 3D printing so that a three-dimensional representation of the diffraction image can be viewed and palpated (Fig. 14 right). The intensities can be seen much better from the 3D model. Nevertheless, sources of error must be considered, such as possible saturation of the camera and non-linear

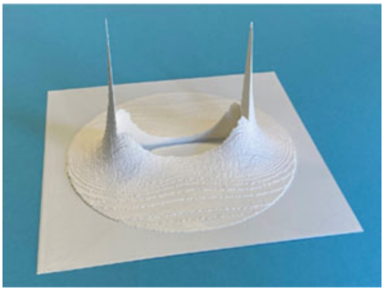


Fig. 13 3D print of the magnetic flux density around a bar magnet

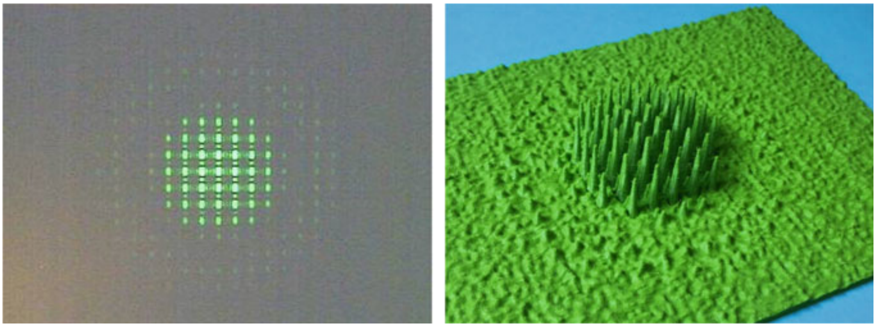


Fig. 14 Webcam image of a diffraction pattern (left) and 3D print made from it (right)

conversions, so that the 3D printout created may only be regarded as a qualitative interpretation aid.

As another example, thermographic images can be prepared for 3D printing in such a way that the height profile of the 3D print corresponds to the temperature profile of the captured object (Fig. 15). In this way, the false colour representation of the thermographic camera is converted into a haptovisual representation of the temperature conditions.

2.6 Use of Digital Media to Train Experimental Skills

In addition, the module teaches how the development of experimental competencies in the classroom can be supported by the use of digital media. For this purpose, various experimental competencies are systematically considered together with a suitable use of digital media as well as appropriate examples. Exemplarily, different multimedia applications for physics education are described regarding their role in physics education as well as their contribution to the promotion of media competence. (Girwidz et al. 2019b).

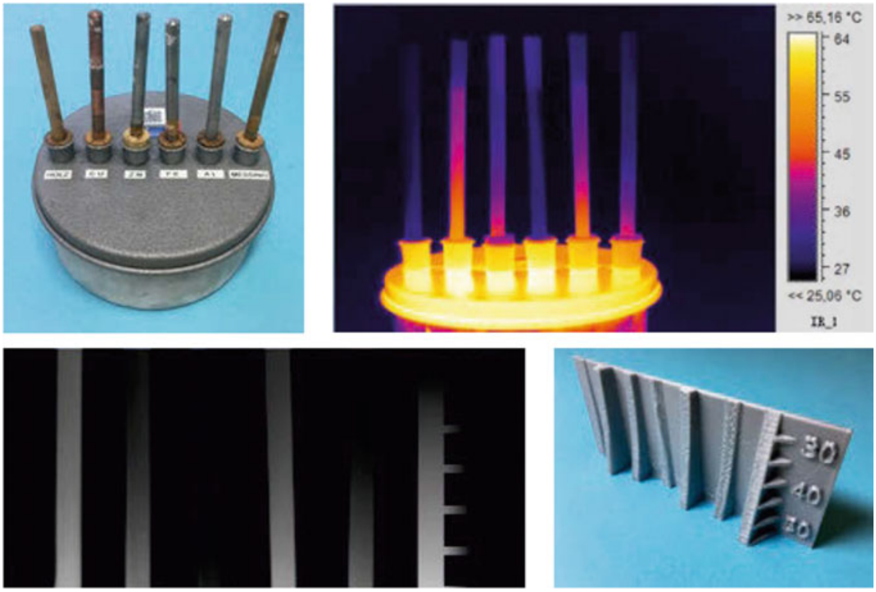


Fig. 15 Thermal images as an example of multicoding and multimodality (Thoms et al. 2020)

2.7 Interactive Learning and Working Material

Interactive task formats can activate and individually support learners. With learning management systems (LMS) such tasks can be organized, structured and provided. The students use various LMS (Moodle, Graasp and WISE) to create digital learning materials for remote inquiry activities (Fig. 16). Differences between the various LMS are also discussed.

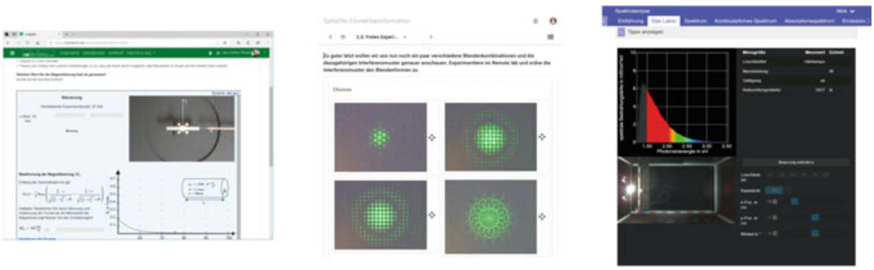


Fig. 16 Exemplary learnings path created by participants and implemented in *moodle* (left), *WISE* (middle), or *Graasp* (right)

3 Results

The effectiveness of the newly developed teaching project on attitudes towards and knowledge about the use of digital media in physics teaching was investigated in a pilot study by means of questionnaire surveys in a pre-post design. The results show a clear gain in technological pedagogical content knowledge (TPACK) for all participants. With regard to the attitude towards the use of digital media, a differentiated picture emerges. While the intention to use digital media in the classroom has increased overall, some participants had a very positive attitude at the beginning and put it into perspective somewhat after the course.

In addition, the students' implementation of what they had learned in the learning materials produced was evaluated. This allowed us to check whether and which of the learning objectives of the seminar were also implemented by the students in the creation of pupil-oriented learning environments. The product analysis showed that all participants have absorbed the essential knowledge content and can now apply it. The marks awarded by the students were also correspondingly good.

Overall, it can be said that the modular design of the seminar is advantageous. The module on theories of multimedia learning was particularly helpful as an introduction. On this basis, the students selected digital media and planned the implementation of their experiment in the LMS. Hence, the students were able to link their course project—the creation of interactive learning and working materials for inquiry-based learning in a remote lab in an LMS—with the weekly meetings and homework. This gave them more time to develop the materials and allowed them to familiarize themselves with the respective learning platform. By presenting their products in plenary, the students received feedback from their peers and lecturers on how to improve their work. At the end of the course, all participants had carried out their own measurements with digital data acquisition systems. The recorded data were processed on the computer and visualised in a pupil-friendly way. Among others, the students prepared selected examples in 3D and printed them out. Compared to three-dimensional visualizations on the screen, three-dimensional printouts can be viewed freely and intuitively from all sides.

4 Discussion

The course on the use of digital media in physics teaching described here was designed in such a way that both general and subject-specific digital competences of prospective teachers are promoted. In developing the course, the TPACK model (Koehler et al. 2013) was primarily used as a basis for designing the development of physics-related digital teaching skills. Now, DiKoLAN—a framework for the digital competencies for teaching in science education—provides an orientation aid that can be used to specify and check the addressed competencies (Becker et al. 2020; Kotzebue et al. 2021; Thyssen et al. 2020). An analysis of the learning objectives pursued in the teaching concept shows that core competencies from all competence areas of DiKoLAN are promoted, albeit to varying degrees (Thoms et al. 2020b).

A special feature of this course was that it was open to students from all semesters of the physics teacher training programme, especially to first-year students. The course was designed accordingly. Neither specific technical knowledge nor pedagogical competences nor special media skills were required. All basics were worked out in the seminar. Nevertheless, advanced knowledge, in word processing (especially paragraph layout) and spreadsheets (especially formulas and diagrams) proved to be helpful. The semester assignment was to create interactive learning and work materials for inquiry-based learning in the distance lab. The knowledge imparted in the individual modules can thus be directly applied. Setting up, using and maintaining the 3D printer must be done conscientiously and requires additional knowledge (Assante et al. 2020). Although models can be created very quickly by students using a computer, the operation of the printer should first be supervised by a professional.

Acknowledgements We would like to thank the Joachim Herz Foundation for accepting us into the *Kolleg Didaktik: digital* and for the associated support for our teaching project.

References

Altherr S, Wagner A, Eckert B, Jodl HJ (2003) Multimedia material for teaching physics (search, evaluation and examples). Eur J Phys 25:7–14. https://doi.org/10.1088/0143-0807/25/1/002

Assante D, Cennamo GM, Placidi L (2020) 3D Printing in education: an European perspective. In: Cardoso A, Alves GR, Restivo T (eds) Proceedings of the 2020 IEEE global engineering education conference (EDUCON), 27–30 April, 2020, Porto, Portugal. IEEE, Piscataway, New Jersey, pp 1133–1138. https://doi.org/10.1109/EDUCON45650.2020

Auer ME, Azad AK, Edwards A, de Jong T (2018) Cyber-physical laboratories in engineering and science education. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-76935-6

Becker S, Bruckermann T, Finger A et al (2020) Orientierungsrahmen Digitale Kompetenzen Lehramtsstudierender der Naturwissenschaften – DiKoLAN. In: Becker S, Messinger-Koppelt J, Thyssen C (eds) Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften. Joachim Herz Stiftung, Hamburg, pp 14–43

Carrillo C, Flores MA (2020) COVID-19 and teacher education: a literature review of online teaching and learning practices. Eur J Teach Educ 43:466–487. https://doi.org/10.1080/02619768.2020.1821184

Dębowska E, Girwidz R, Greczyło T et al (2013) Report and recommendations on multimedia materials for teaching and learning electricity and magnetism. Eur J Phys 34:L47–L54. https://doi.org/10.1088/0143-0807/34/3/L47

Fernández-Batanero JM, Montenegro-Rueda M, Fernández-Cerero J, García-Martínez I (2020) Digital competences for teacher professional development. Systematic review. Eur J Teacher Educ 1–19. https://doi.org/10.1080/02619768.2020.1827389

Girwidz R, Hoyer C (2018) Didaktische Aspekte zum Einsatz digitaler Medien – Leitlinien zum Lehren mit Multimedia, veranschaulicht an Beispielen. In: Meßinger-Koppelt J, Maxton-Küchenmeister J (eds) Naturwissenschaften digital: Toolbox für den Unterricht. Joachim Herz Stiftung Verlag, Hamburg, pp 6–23

Girwidz R, Thoms L-J, Pol H, López V, Michelini M, Stefanel A, Greczyło T, Müller A, Gregorcic B, Hömöstrei M (2019a) Int J Sci Educ 25:1–26

Girwidz R, Thoms L-J, Pol H et al (2019b) Physics teaching and learning with multimedia applications: a review of teacher-oriented literature in 34 local language journals from 2006 to 2015. Int J Sci Educ 25:1–26. https://doi.org/10.1080/09500693.2019.1597313

Girwidz R, Watzka B (eds) (2018) Arduino, Raspberry Pi & Co (Naturwissenschaften im Unterricht Physik, 167). Friedrich, Seelze

Heradio R, de La Torre L, Galan D, Cabrerizo FJ, Herrera-Viedma E, Dormido S (2016) Virtual and remote labs in education: a bibliometric analysis. Comput Educ 98:14–38. https://doi.org/10.1016/j.compedu.2016.03.010

Hoyer C, Girwidz R (2018) A remote lab for measuring, visualizing and analysing the field of a cylindrical permanent magnet. Eur J Phys 39:65808. https://doi.org/10.1088/1361-6404/aae35a

Hoyer C, Thoms L-J, Girwidz R (2020) Lehren mit Multimedia, Fernlaboren und 3D-Druck im Physikunterricht. In: Habig S (ed) Naturwissenschaftliche Kompetenzen in der Gesellschaft von morgen. Universität Duisburg-Essen, Essen, pp 979–982

Hoyer C, Girwidz R (2020) Animation and interactivity in computer-based physics experiments to support the documentation of measured vector quantities in diagrams: an eye tracking study. Phys Rev Phys Educ Res 16. https://doi.org/10.1103/PhysRevPhysEducRes.16.020124

http://did.physik.lmu.de/sims/magneticfield/index_de.html

http://myrcl.net

http://rcl-munich.informatik.unibw-muenchen.de/

Koehler MJ, Mishra P, Cain W (2013) What is technological pedagogical content knowledge (TPACK)? J Educ 193:13–19. https://doi.org/10.1177/002205741319300303

Kotzebue L von, Meier M, Finger A, Kremser E, Huwer J, Thoms LJ, Becker S, Bruckermann T, Thyssen C (2021) The Framework DiKoLAN (Digital Competencies for Teaching in Science Education) as Basis for the Self-Assessment Tool DiKoLAN-Grid. Educ Sci 11:775. https://doi.org/10.3390/educsci11120775

Maletić S, Ivančev-Tumbas I, Brossas A et al (2021) Overview of Erasmus+ NETCHEM project: ICT networking for overcoming technical and social barriers in instrumental analytical chemistry education. Environ Sci Pollut Res Int 28:2479–2483. https://doi.org/10.1007/s11356-020-11506-4

Mayer RE (ed) (2014). The Cambridge handbook of multimedia learning. Cambridge University Press, New York. https://doi.org/10.1017/CBO9781139547369

Mayer P, Girwidz R (2019) Physics teachers' acceptance of multimedia applications—adaptation of the technology acceptance model to investigate the influence of TPACK on physics teachers' acceptance behavior of multimedia applications. Front Educ 4:73. https://doi.org/10.3389/feduc.2019.00073

Persano Adorno D, Pizzolato N (2020) Teacher professional development in the context of the "Open Discovery of STEM laboratories" project: is the MOOC methodology suitable for teaching physics? J Phys: Conf Ser 1512:12030. https://doi.org/10.1088/1742-6596/1512/1/012030

Schnotz W, Bannert M (2003) Construction and interference in learning from multiple representation. Learn Instr 13:141–156. https://doi.org/10.1016/S0959-4752(02)00017-8

Sweller J (2010) Element interactivity and intrinsic, extraneous, and germane cognitive load. Educ Psychol Rev 22:123–138. https://doi.org/10.1007/s10648-010-9128-5

Thoms L-J, Girwidz R (2015) Training and assessment of experimental competencies from a distance: optical spectrometry via the Internet. Il Nuovo Cimento C 38:1–10. https://doi.org/10.1393/ncc/i2015-15113-3

Thoms L-J, Girwidz R (2017) Virtual and remote experiments for radiometric and photometric measurements. Eur J Phys 38:55301–55324. https://doi.org/10.1088/1361-6404/aa754f

Thoms L-J, Hoyer C, Girwidz R (2020b) Mit digitalen Medien experimentelle Kompetenzen fördern und komplexe Datenauswertungen schulen. In: Becker S, Messinger-Koppelt J, Thyssen C (eds) Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften. Joachim Herz Stiftung, Hamburg, pp 111–114

Thoms L-J, Hoyer C, Girwidz R (2020) Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften (Becker S, Messinger-Koppelt J, Thyssen C (eds)). Joachim Herz Stiftung, Hamburg, pp 111–114

Thyssen C, Thoms L-J, Kremser E, Finger A, Huwer J, Becker S (2020) Digitale Basiskompetenzen in der Lehrerbildung unter besonderer Berücksichtigung der Naturwissenschaften. In: Beißwenger M, Bulizek B, Gryl I, Schacht F (eds) Digitale Innovationen und Kompetenzen in der Lehramtsausbildung. Universitätsverlag Rhein-Ruhr, pp 77–98. https://doi.org/10.17185/duepublico/73330

Teacher Professional Development

Implementing Research-Based Intervention Modules for Teachers of Quantum Mechanics

Marisa Michelini and Alberto Stefanel

Abstract The introduction of quantum mechanics in school curriculum is now a need, but teachers are not prepared for this task. Lack of basic concepts is intertwined with a scholastic tradition that has always either neglected the topic or faced it in a historical key, with simplified descriptive approaches. We used a research-based educational proposal as key material for an intervention module for teacher education, integrating the basic contents of the theory and their teaching. The outcomes indicate that involved teachers acquired significant competencies in planning and conducting activities with students on the base nuclei of the quantum mechanics.

1 Introduction

Almost all the national curricula of Europe and in many of the Latin-American, Asian and African countries include quantum physics issues. However, teaching/learning Quantum Mechanics (QM) in secondary school is a multidimensional problem and a great actual debate concerns educational approaches, topics, goals, and target students (Zollmann 1999; Phys Educ 2000; Stadermann et al. 2019; Am J Phys 2002; Pospiech et al. 2008; Henriksen et al. 2014; Krijtenburg-Lewerissa et al. 2019). As is well known, the different interpretations of quantum mechanics have given rise to different approaches and ways of looking at and proposing quantum phenomena and concepts (Michelini and Stefanel 2021; Styer et al. 2002; Cataloglu and Robinett 2002). Added to this is the fact that most of the teachers are not prepared for this task. Shortcomings in basic concepts are intertwined with a scholastic tradition that has always either neglected the topic or faced it in a historical key, with simplified and transmissive approaches, descriptive narratives of experiments, and theoretical hypotheses (Pospiech et al. 2008; Krijtenburg-Lewerissa et al. 2019). Different strategies have been adopted to prepare teachers for teaching quantum mechanics in high school (Pospiech 2000a, 2000b; Justi et al. 2005; Olsen 2002; Asikainen 2005; Asikainen and Hirvonen 2009; Leinonen et al. 2020). Studies explored effective ways

M. Michelini · A. Stefanel (✉)
Physics Education Research Unit, University of Udine, via delle Scienze 206, 33100 Udine, Italy
e-mail: alberto.stefanel@uniud.it

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_7

to build competences on the conceptual contents (CoK in CK) and to overcome the lack of specific disciplinary preparation characterizing a cohort of physics teachers (for instance more than 2/3 of Italian teachers have a degree in math without any specific formation on quantum mechanics) (Borello et al. 2002; Michelini 2020), on the related pedagogical contents knowledge (PCK) (Shulman 1986). Other studies focused on competences in the use of technologies (TPCK) particularly important in this field as mediators between phenomenology and theory (Taylor 1998; Robertson and Kohnle 2010; Mason et al. 2015; Kohnle 2015; McIntyre 2012; Michelini et al. 2016). The challenge of preparing teachers to face quantum mechanics with their students poses in a critical and more pressing way than in other areas of physics the dilemma of whether to prioritize the preparation of the contents or the teaching methods of those contents. This issue is emphasized when the teacher formation aims to produce didactic innovation on teaching methods and tools as well as on contents (Pospiech 2003; Michelini et al. 2004a; Stefanel et al. 2004; Michelini et al. 2017).

We have dealt with this problem by proposing a quality teacher formation in which physics education research (PER) plays a central role: creating an educational context in which a research attitude is reproduced; proposing the materials developed by the research as objects of study and its methodologies as methods of working with students and in the analysis of their learning paths (Taber 2007; Michelini et al. 2004b, 2013a). These assumptions are the basis of development and experimentation of a research-based Formative Intervention Module (FIM) for teachers to support the introduction of QM in secondary school.

According to our research approach on teacher formation and preparation (Michelini et al. 2013a, 2017), we have addressed this issue by choosing to implement a structural integration of conceptual analysis of the fundamental nuclei of quantum theory and of its educational reconstruction implemented and developed in research-based didactic paths and materials (Ghirardi et al. 1995; Michelini et al. 2000; Michelini 2008), validated by research experiments in school. The aim of this contribution is to highlight the formative role of didactic research in teacher training in the specific topic of QM didactics. We present in the following the main common characteristics of the FIM on QM and discuss the main outcomes of researches conducted with the trainee teachers attending our FIM.

2 Research Questions

As mentioned, our research on teacher formation is aimed at studying the effectiveness of proposing contents (CoK) and how these contents can be addressed with students (PCK) (Shulman 1986; Michelini et al. 2013a, 2017), in an integrated way, through the discussion, analysis, and testing of research-based and validated proposals. Here we focus on the role of these actions and in particular, we aim to answer the following research questions:

- RQ1: How do conceptual and educational issues involve and influence pre-service and in-service teachers involved in the FIM?
- RQ2: How to produce PCK in quantum mechanics?
- RQ3: Which competences are developed by our FIM?

3 The Structure of the Formative Module on QM

The FIM was developed through a design-based research process with subsequent revisions implementing it both in the pre-service and in the in-service teacher education. The FIM on quantum mechanics was designed for activating, in all phases of teacher preparation and formation, a strong integration of CK/CoK and PCK. This was accomplished through: the analysis and discussion of research-based proposals documented in PER literature; the exploration of a research-based educational path focused on basic nuclei of the QM theory; the use of its tutorials; the design of activities to be experimented with the students; the monitoring of their educational paths with research tools and methods developed in didactic laboratory activities.

The rationale of the FIM can be synthesized in the following four parts, referring the reader interested in further information to the references of previous works (Michelini et al. 2004a; Stefanel et al. 2004; Michelini et al. 2013b, 2017; Michelini and Stefanel 2021; Francaviglia et al. 2012):

(1) The analysis of the conceptual approach of the proposal to QM and its basic formalism by means of the tutorials that are an integral part of it focused on (Ghirardi et al. 1995; Michelini 2008; Michelini et al. 2000, 2008);
(2) The discussion of the fundamental nuclei of QM and comparison of the main approaches to quantum mechanics and research-based teaching proposals (Michelini and Stefanel 2021);
(3) The planning of an educational path and relative educational materials (tutorials and questionnaires) to be implemented in classroom experiments, such as re-elaboration, extension, modification of the reference proposal, and micro-teaching on different approaches
(4) Experimentation of the didactic proposal, monitoring and analysis of learning outcomes by means of research method of students' reasoning and learning paths (Michelini et al. 2004a; Stefanel et al. 2004; Michelini et al. 2017).

In the following subsections, we discuss the individual parts.

3.1 A Research-Based Proposal on Conceptual Dirac Approach to QM

The design of the FIM on QM for teacher formation was achieved by a preliminary research consisting of the design of formative modules for students and implementing each in an iterative way by means of Design Base Research (The Design-Based Research Collective 2003). The didactic materials of the FIM were the educational proposal designed, the tutorial developed for the activities with the students, and the research works published, in which the path and materials, as well as the learning outcomes of the students, were documented. Some basic choices characterize it and make it particularly effective both as a reference and for a discussion on the conceptual foundations of QM, integrated with the ways in which they can be addressed with students, constituting a solid reference for didactic planning of teachers in formation.

The first basic choice of our proposal on QM is to focus on the crucial nodes of the theory, on the peculiarities of quantum analysed, on the concepts that most characterize it, distinguishing it from classical physics. The approach, in accordance with the Model of Educational Reconstruction (MER) of Duit et al. (2005), therefore aimed at introducing from the beginning the concepts of state, of superposition, the distinction between state and property, and the non-epistemic indeterminism typical of QM vs the epistemic indeterminism that characterizes the use of probability in classical physics.

The Dirac approach was chosen for the following reasons: it lends itself to the treatment of phenomenologies described with two-state systems within the reach of students such as optical polarization, in which students can appropriate the formal bases and attribute a central role to the superposition principle. An extensive analysis of the approaches to quantum mechanics was part of the research that led to this choice (Zollmann 1999; Special Issue on Quantum Physics 2000; Special Issue on Quantum Mechanics 2002; Pospiech et al. 2008; Henriksen et al. 2014; Krijtenburg-Lewerissa et al. 2019; Michelini and Stefanel 2021).

The phenomenology of photon polarization was the context for discussing these concepts. In other areas such as that of the spin, the double-slit, or the Mach-Zender interferometer (Michelini and Stefanel 2021), polarization can be treated in a rather in-depth and relatively simple way from a formal point of view, limiting itself to the use of two-dimensional state vectors on a real field (Ghirardi et al. 1995; Michelini et al. 2000; Michelini 2008). It also has the undoubted advantage of being easily explored directly by students with low-cost kits made up of polaroids and birefringent crystals, which we have developed as materials to be used with students and offered to schools for autonomous experiments (Michelini et al. 2006). The approach followed (Ghirardi et al. 1995; Michelini et al. 2000; Michelini 2008) proposes to students the analysis of the phenomenology of the interaction of light with Polaroid and birefringent crystals in the form of an exploratory problem-solving. In this context, students construct an operational definition of polarization as a (transverse) property of light, which is recognized through the variation of intensity of the light transmitted by a polaroid-analyser, but which is a different property from the intensity itself.

The Malus experiment, which conceptually organizes the phenomenology, is then reinterpreted by students in probabilistic terms, assuming the photonic nature of light. The use of the JQM applet (Michelini et al. 2016), specially designed and built to support the educational path, allows students to explore single-photon phenomena in a simulated environment by activating a PEC strategy.

The possibility of making certain predictions on the photons interaction with a Polaroid, at least in the most trivial cases (Polaroid with parallel/orthogonal permitted direction) allows defining the concept of state as the set of information that allows predicting the a priori probabilities of the different possible mutually exclusive events, which are the result of the measurement. The (dynamic) properties that are produced upon measurement (the polarization along a given direction) are mutually exclusive and are incompatible with those possessed by photons before the measurement (except in cases where the results are certain). An iconographic representation of the polarization properties helps students to assume the perspective of QM, for which we need to distinguish between the concept of state and the property of a system in that state, in contrast to classical physics where we can always identify the state of a system with a set of values of its properties. It also provides students with a formalized, non-mathematical, tool to build hypotheses that can be tested using the JQM simulator. In particular, it is possible to discuss the distinction between a pure quantum state and a statistical mixture of states. The existence of incompatible properties is identified with the physical meaning of the uncertainty principle. In the context of the interaction of photons with Polaroid, the concepts of non-epistemic indeterminism and the identity of quantum systems are discussed. The delicate issue of the impossibility of attributing a trajectory to quantum systems is addressed by discussing the interaction of photons with birefringent crystals. This simple context also allows us to highlight the non-local nature of quantum interactions and to introduce the concept of entanglement, even if limited to the case of entanglement between polarization states and translational states. The contexts analysed also allow us to discuss the knot of macrostates, and the consequences deriving from the assumption that in filtering from a Polaroid, photons are attributed more polarization properties at the same time, that is the perspective logically equivalent to that of hidden variable theories, highlighting the non-classical nature of the analysed of the systems considered.

The salient steps of the path briefly outlined here are subsequently rediscussed starting from the reformulation of Malus's law as a square of the scalar product between a vector that encodes information on the state of preparation and the one that encodes information on the state of detection of a photon, for example, it has passed a polarization test. The expression of the superposition principle is an immediate consequence of the possibility of representing the state of a system with a vector. Its interpretation is still explained in the phenomenology investigated. Malus's law expressed as a scalar product of state vectors allows us to introduce the concept of projector and its formalized representation, which forms the basis for constructing the representation of physical observables using linear operators.

In the activities with students, the exploratory-conceptual part of the didactic path and the one in which formalization is introduced has always been proposed with a two-cycle spiral path, thus analysed the learning of the many students who encounter difficulties in handling the formal constructs of physics, while highlighting competencies on conceptual aspects. On the other hand, didactic sequences, even developed, in which the formalization is introduced contextually to the analysis of the concepts have not yet been experimented with the students.

All the salient steps of the path have been operationally translated into tutorials based on an inquiry-based strategy, with the use of stimuli questions that activate conceptual reflection, the exploration of the consistency of theoretical hypotheses and the consequences that derive from these hypotheses. In the experiments with students, questionnaires were also developed that investigate the students' conceptions of the nodes addressed in variational terms, according to the pre/post-test method. As anticipated, tutorials, pre/post-test (Michelini et al. 2008), and papers presenting the educational path, as well a web environment with supporting material for teachers (Michelini et al. 2013b; Michelini 2021) were offered to teachers in formation during the FIM on QM. Activities were held both in presence, and conducted online, as well as in blended mode. In a first stage, the proposal was presented and discussed with teachers in formation stressing the conceptual knots and the educational strategies able to overcome them. In a second stage, the teacher in formation experienced the same path of students using the tutorials (Michelini et al. 2008, 2013a; Michelini 2008) in experiential activities performed in educational labs in presence or in an e-learning environment: filling and discussing the educational role of the tutorial, the main problem expected with students, proposing how to change the tutorial itself.

3.2 Comparison of Different Research-Based Approaches on QM

The effective appropriation by trainees of an innovative teaching proposal, such as the one outlined in the previous subsection, requires the acquisition of critical tools in knowing how to evaluate strengths and criticalities, competence in knowing how to define the learning objectives that it promotes, rather than the conceptual knots it leaves open. For this reason, the FIM on the QM includes an important part in which the trainee teachers were offered the comparative analysis of different research-based proposals validated in research experiments with students. In the choice of materials to be proposed for analysis to the trainee teachers, therefore, we look at reviews on researches in the teaching of QM at introductory level (Zollmann 1999; Pospiech et al. 2008; Henriksen et al. 2014; Krijtenburg-Lewerissa et al. 2019; Michelini and Stefanel 2021; Styer et al. 2002) as well as to the original works (Special Issue on Quantum Physics 2000; Special Issue on Quantum Mechanics 2002; Pospiech 2000b; Taylor 1998; McIntyre 2012; Ghirardi et al. 1995; Michelini et al. 2000). The double value was to offer an updated state of art on researches on teaching/learning QM, including the validated different approaches, the main student difficulties, and the critical points of the different paths compared, and at the same time providing analysis criteria based on research.

In the activities, carried out completely online, these materials were made available to teachers in the e-learning environment as references for: (A) a forum discussion of the main teaching approaches on QM; (B) the detailed analysis and critical discussion of a research proposal, chosen from those proposed in the reviews or even identified by the students, provided it is documented in the literature. In presence, these discussions and analyses were enriched by a face-to-face exchange involving at the same level of the researcher conducting the course and trainee teachers. The tasks required of the trainee teachers were: (A) to post at least three contributions, one for each of the three main approaches to QM (historical, formal, conceptual (Michelini and Stefanel 2021)) on learning/teaching values (such as better learned concepts, role of the formalism, contexts addressed, generality of the approach …) and criticality of each of them (student learning problems, fundamental aspects left open, feasibility …); (B) prepare a document which summarizes in 1–2 pages the critical analysis of a research-based educational path on quantum mechanics, documented in the literature, both as regards the approach as well as the learning outcomes with the students. Both tasks aim above all to prepare a physics teacher who bases his professional competence on the research literature in didactics of the specific topics taught. The first task aims in particular to prepare a teacher who knows and is updated on the different perspectives that PER has proposed to tackle QM at school. He also becomes competent in evaluating the role of learning of each approach on the basis of objective evidence and not of a priori assumptions or empirical experience (important, but not sufficient to improve teaching professionalism). The second task prepares the teacher in a detailed analysis of an approach different from the one dealt with in-depth in the other parts of the FIM. The task requires in fact to choose an approach among those documented in reading, to analyse the contents treated, how they are addressed and the didactic tools used to address them, to discuss briefly the methods of analysis of learning and learning outcomes, and to include a critical comment on the weaknesses that emerge from the previous analysis (Michelini et al. 2017).

3.3 Planning Intervention in School on QM

The trainee teachers were requested to plan an educational path and relative educational materials (tutorials and pre/post-test), starting from those discussed and analysed in the FIM. This phase included homework for each trainee teacher, collective discussion in didactic laboratory, and specific work with the tutor. The planning activity was supported with the material offered during the course, the web environment offered as repository where the teachers can find a presentation of the reference path discussed in Sect. 3.1, documentation of the experiments conducted with students, and the materials used. The structure of the environment constitutes a reference for teachers' planning. Moreover, two rubrics were set up to aid teachers in the planning activity: a first focused the attention on the main knots of the topic, as suggested by the perspective of the MER; the second asks them to organize these main knots in the form of a sequence of contents, an organizational map, a sequence of activities and related questions to pose to the students. Trainee teachers using these rubrics acquire gradually confidence with the planning activities, focusing on the main point required in the planning recommendations. The next step in the FIM involved the development of tutorials and pre/post-test. This is a crucial step of the design, so that a sequence of contents identified as relevant for a didactic path, their organization in a more or less organic sequence, acquires coherence in the passages from one topic to another. It becomes an effective didactic path to address the specific topic considered, overcoming the students' learning problems, and aiming at specific and evaluable objectives. It is also an important phase for teachers to acquire experience in how to build pre/post-tests to evaluate the change in students' conceptions. In the case of quantum mechanics, this is an even more difficult challenge than in the different contexts of classical physics in which the reference to phenomenologies known to students allows to construct questions that can be proposed both before and after a training intervention, therefore able to monitor if and how students' conceptions change.

3.4 Experimentation in School

The last stage of the FIM was the experimentation in school of the educational path designed in the previous phase. In this phase the in-service teachers experimented usually with their own students, the prospective teachers were housed in welcoming teachers' classes.

In the experimentation in school, the trainee teachers concretize the ownership of the innovative path that they designed, by contextualizing it in a specific school context, acquiring first-hand experience on the typical reactions of students, their difficulties, and the ways to help them overcome these difficulties, their typical arguments and ways to enhance those that activate positive learning progression of entire class groups in collective stages of comparison and sharing between peers.

This phase was completed by accompanying the teachers in the analysis of tutorials and questionnaires filled out by students carried out with typical research methods. This is, perhaps, one of the most important contributions that the research world can offer to teacher formation.

4 Research Context, Instruments, and Methods

The FIM was developed through a design-based research process with subsequent revisions from 1999 till now in different formative contexts. The first design and implementation of the FIM were done in the context of the pre-service teacher formation in 2000 when the biannual School of Specialization for secondary teachers was institutionalized first in Italy. We designed and implemented a first version of the FIM including three courses, each of two cts: a first course focused on the discussion of basic concept of QM from the point of view of discipline (CoK part); a second course focused on the analysis of the educational path discussed in 3.2 including the comparison between different approaches (PCK part); an educational lab focused on the design activity and on the discussion of the partial and final results of experimentation in school carried out as apprenticeship, experiential and situated part structurally integrated in the FIM (Michelini et al. 2004a). Subsequent adjustments were made until 2015 to improve the integration of the CoK and PCK parties in the following years until the suppression in Italy of all types of initial formation of secondary teachers. The face-to-face activities were supported by an e-learning platform where the trainees find educational material and discussed the basic concepts of QM as the concepts of state, uncertainty, incompatibility, impossibility to attribute a trajectory to a quantum system.

This activity conducted in blended mode (Stefanel et al. 2004) provided us with the skills to implement the FIM in e-learning from 2007 up to today, for in-service teachers, in the context of the two-year II level master's degree IDIFO of the national Scientific Degrees Plan (PLS). In that frame, the FIM was re-organized realizing a structural integration of the CoK and PCK in each of the parts as presented in Sect. 3 (Michelini et al. 2004a). In particular, the basic concepts of QM are discussed in two courses analyzing the educational path presented in Sect. 3.1 and comparing the different approaches from literature. The design and experimentation activity differed from that carried out with the pre-service trainees due to the need to provide for an initial phase of comparison to discuss with the teachers in service:

- Their experiences of interaction with students in dealing with physics in general (the strategies that worked, the difficulties they encountered in dealing with some conceptual knots with the students, the choices of content to deal with the students, the level of complexity, deepening and formalization, students' reactions, their difficulties)
- Any previous experiences, on the specific topic (from a side to enhance and share the experience with the other trainees both on the educational path choices made, and on the students' reactions and their learning paths, and from another side to give a research-based critical feedback)
- The difficulties in implementing national curricula and preparing students for the state exam, often motivated by the limited time available
- The reluctance of teachers to abandon or at least change their teaching style, their curricular choices, refer to school traditions more or less rooted in time, and often rely on textbooks, especially where they feel less prepared, as is the case of modern physics in general and even more specifically in the specific of QM
- Distrust in adopting innovative proposals citing difficulties of time, content, different from those included in the curricula and final or marginal state exams with respect to them.

The situated activity also differed from that of the trainees, as the in-service teachers have almost entirely experimented the educational paths designed in the FIM in their own schools with their own students, thus inserting the project within their own annual program.

Table 1 summarizes the contexts where the FIM was implemented, the relative credits (cts), and the number of involved participants.

Table 1 Types of contexts and participants of the FIM

Academic Years	Context of the FIM	Credits (cts)	No. of participants
2000–2010	School of specialization	6	45
2010–2015	Formative apprenticeship	6	15
2007–2020	Master IDIFO	46	109

5 Instruments for the Analysis of the Progression of Teacher Formation

To document some of the main educational outcomes of the FIM and answer the research questions that are the specific objective of this work, we analysed the following materials produced by trainees:

(A) The questionnaire, which the teachers filled out both in the preliminary phase (as a pre-test) and as an intermediate test at the end of the training phase at the university and before starting the experimentation activities in the classrooms with the students

(B) The contributions posted by trainees in web forum, on the Conceptual Knots of quantum mechanics (reflection on CoK) and on how these nodes can be addressed with students (reflection on the PCK)

(C) The reports that the trainee teachers have produced at the end of their formative path as documentation of the experiments carried out in the classroom.

The questionnaire submitted to the teachers was developed specifically for teacher formation on QM (Michelini and Stefanel 2021; Francaviglia et al. 2012). It is composed of eight open questions, divided into two parts. The first five questions stimulate reflection on what are the founding contents of QM, how the concepts of state and properties change from classical physics to the QM and what characterizes quantum behavior in relation to the classical one (part CoK). The second part (three questions) stimulates a reflection on which contents to include in the teaching of the QM, which not to be included, how to deal with them (privilege formalism, historical aspects, founding concepts…). In the formative activities, the questionnaire allowed to outline a "fil rouge" for discussions on QM and teaching/learning QM. It also made it possible to monitor the specific background (knowledge, skills, and even personal beliefs) the trainee teachers faced the formative path and how this has produced profound changes in their specific competencies. The questionnaire open answers of 123 teachers were analysed according to criteria of qualitative research (Denzin and Lincoln 2011), operationally defining categories of answers through typical answers of teachers.

The formative activities carried out in person, and even more so, those carried out online were supported with web forums, activated by stimulus requests from the researcher conducting the course and/or by the reflection activated by filling in the questionnaire. The analysis of the contributions posted in the web forums is here focused on providing information on the CoK developed by the teachers trained in the FIM on the founding aspects of the QM. Analysis contributions were posted in the web forums of 164 FIM participants (of different cohorts of trainees and in-service teachers) using the web-interaction categories defined by Angell et al. (Hara et al. 2000), the replication index (Wiley 2004), as well as by carrying out a correlation analysis between the contents addressed (Stefanel et al. 2004; Michelini et al. 2013b).

Trainee teachers produced final reports after the conclusion of the FIM, which were evaluated in the Specialization School or in the IDIFO Master's course for in-service teacher professional development: where each trainee teacher had to choose two themes of different domains for design and experimentation in schools. These reports were drawn up on the basis of reference rubrics and had as a relevant part the presentation of at least two training courses experimented with the students. Here we consider the educational paths on QM designed and experimented in the FIM, compared with the educational paths on other topics (paths on a mathematics topic for instance) (Michelini et al. 2004a; Stefanel et al. 2004).

To compare very different projects implemented by the trainees, three different rubrics were designed and used for the analysis of the educational paths: the first concerned the design elements; the second the contents addressed; the third methods of experimentation and learning monitoring (Michelini et al. 2004a). Each rubric included different categories, each declined in elements or components that were expected. Figure 1 shows the categories and components of the first rubric. To each component was assigned a score (from 0: element absent, to 3: element valorized in the report) and then the average score was assigned to each component of the rubric. Comparing the project realized within the FIM on QM with that realized within courses other than FIM.

In that way, we obtained information on PCK developed by teachers evidencing the main added values gained from the FIM in comparison to the other course followed by the trainees. For the students of the Master courses, it was only possible to take into consideration the didactic projects carried out on the QM, as there was no possibility of a comparison with other projects carried out by the teachers themselves. Therefore, only the aspects in which the projects of the in-service teachers differed from those of the teachers in first training were identified and stressed.

Categories	Components			
Context	Pupils presentation	The program carried out before	Used methodology	Ability in lab work
Behavior	Description	Documentation	Pupils' questions, answers, ideas	Final critical considerations
Test	Presentation	Results analysis	Results discussion	
Worksheets	Presentation	Pupils' sentences analysis	Use evaluation	

Fig. 1 Rubric for the analysis of the educational projects designed by trainees (Michelini et al. 2004a)

6 Data and Outcomes

Here we can only discuss some main results, supporting them with a few summary data referring to the works in the bibliography and cited punctually below for further information (Pospiech et al. 2008; Michelini 2020; Michelini et al. 2016, 2017, 2013b; Michelini et al. 2004a; Stefanel et al. 2004; Michelini and Stefanel 2021; Francaviglia et al. 2012).

From the analysis of 123 questionnaires completed at the beginning of the FIM, it emerged that over 80% of teachers, before starting the FIM, indicated the Heisenberg uncertainty relations as peculiar elements of the QM, the measurement as perturbation/disturbance that cannot be eliminated on a microscopic system the outcome of which is indeterminate due to lack of information on the system-apparatus interaction process. The typical concepts of the old quantum theory were also considered tout court as characteristic concepts of QM (typical: quantization in the old quantum theory is equivalent to discretizing physical quantities and not, as in QM, associating an operator with an observable). The same contents were also indicated as central to be addressed with students at school. No one indicated the concepts of state, superposition, incompatibility as central to QM.

The analysis of the web forums implemented in the FIM courses, involving 164 trainees and in-service teachers in formation, revealed one-half of "elementary contributions", but more than one-third of "deep contributions" and the remaining as "judgments", according to Angell et al. classification codes (Hara et al. 2000). The depth replication index (Wiley 2004) was low (from 1.4 to 2.5). Considering the contents, five clusters emerged, showing a systematic improvement in the CoK competencies in treating the following concepts: quantum state and difference with CM state; superposition principle and its formal expression; concepts of compatibility; epistemic/non-epistemic indeterminism; impossibility to attribute a position/trajectory to a quantum particle (Michelini et al. 2004a; Stefanel et al. 2004; Francaviglia et al. 2012). Some examples from the questionnaire administered as intermediate test give the measure of the competencies developed:

- Concerning the change in meaning and the role of measurement from classical to quantum physics: "In Classical Physics measurement of a property records a characteristic of the system that was pre-existing to the measurement itself. In quantum mechanics, on the contrary, the measurement plays an active role, in the sense that it contributes to determine the quantity that is measured".
- Concerning predictability of the measured properties: "the result of a measurement is not predictable in Quantum Mechanics"; "the value obtained in a measurement cannot be predicted in a deterministic way".
- Concerning stochastic distributions of results: "if we make infinitely many copies of a state and perform infinitely many measures of the same observable, we never obtain the same result, but a distribution of results".

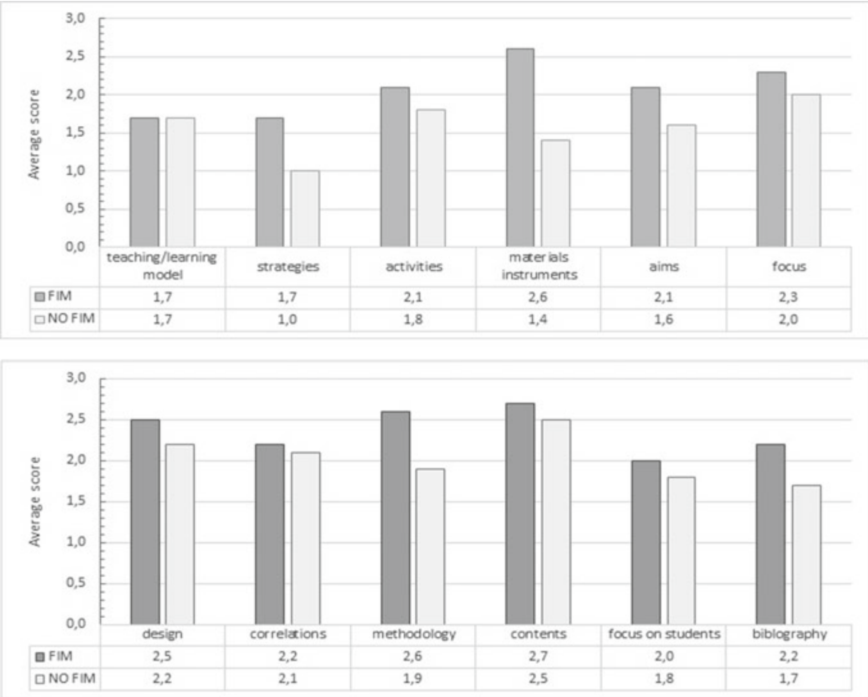


Fig. 2 Distributions of mean scores attributed to the elements of the rubric used to analyse and compare educational projects on QM developed inside the FIM and educational projects developed on other topics

The analysis performed on the reports on a sample of 45 trainees provides important information on the competencies developed by trainee teachers. Figure 2 summarizes some of the main outcomes of the FIM, comparing the average scores obtained for design and experimentation in the quantum mechanics educational projects designed and implemented in school, with those obtained by applying the same rubric to the analysis of educational projects designed by each trainee teacher on other topics outside the FIM. A greater focus emerged on the students' learning and on the materials and tools used, laboratory approach based on real and virtual experiments. This is also indirectly confirmed by the documentation of the students' learning in the experiments carried out in the apprenticeship activities. These results indicate that the acquired contents (the CoK) have become didactic competence (PCK) in the planning of the interventions and PCK in action in the school experiments. The didactic paths designed in the FIM were logically consistent on a methodological, didactic, and disciplinary level. They are always supported by relevant literature and by substantial consistency between the different parts (discussion of the setting, block diagram of the activity, description of the path, map, and tutorials) (Stadermann et al. 2019).

The paths designed and tested by the in-service teachers in the FIM paid similar attention to the students, to the teaching methodology, and to the tools. These projects differ from those of prospective teachers for fewer innovative elements, tending rather to recover the historical dimension within the educational path, which overall had a broader temporal development. Also in this case the students' educational outcomes were documented with typical research methodologies and confirmed a profound change in the teachers' perspective on what are the relevant concepts of QM, what is the way of thinking perspective that it entails, what aspects it is important to treat in school, and what is its cultural value.

7 Conclusion

A research-based formative module was designed to prepare physics teachers of late secondary school for teaching/learning quantum mechanics. According to the design-based research approach, it was adapted according to the feedback of successive implementation cycles. It is characterized by a strong integration of basic concepts of quantum mechanics and the teaching of these concepts. The core of the formative module was in fact the analysis of a research-based educational path on quantum mechanics following a Dirac approach, tested and documented in literature, and the comparison and discussion of different other approaches documented in literature. Through the analysis of the answers of trainee teachers to the items posed in a questionnaire designed to stimulate their reflection on basic concepts of QM (CoK part) and its didactic (PCK part), the analysis of discussion in the web forum, and of the report produced by trainee teachers at the end of the formative path, we can obtain answers to our research questions.

The trainee teachers passed from a view based on the old quanta theory to a view of quantum mechanics related to the concept of states and superposition, from a traditional descriptive «historical» approach to an educational path focused on basic concepts of QM, from a transmissive approach to approaches focused on students learning, monitored with research instruments (RQ1). The added values of the formative module were the analysis and discussion of research-based educational proposals (from literature), the comparison of different research-based proposals, the discussion on learning knots, the design activity, and implementation in school. All these aspects contributed to modify the view of trainee teachers on QM and their PCK (RQ2), and in particular:

- The questionnaire the trainee teachers filled out on conceptual nodes allowed them to reflect on the disciplinary point of view (CoK) and didactic one (PCK) on the different theoretical perspectives of old physics of quanta compared to the quantum mechanics theory, on the centrality of the distinction between state and property in QM and on the quantum behavior of phenomena (Michelini and Stefanel 2021; Francaviglia et al. 2012).

- The discussion in the forums developed specific CoK on the founding contents (change of perspective from classical physics to quantum mechanics, role of measurement in the two, quantum behavior, superposition principle and state concept, predictability of measures outcomes) (Stefanel et al. 2004; Michelini et al. 2017; Taber 2007)
- Didactic planning and experimentation in the classrooms transformed CoK into PCK and PCK in action (Michelini 2020; Michelini et al. 2016, 2017, 2013b; Michelini et al. 2004a; Stefanel et al. 2004; Michelini and Stefanel 2021; Francaviglia et al. 2012).

The main competencies developed by trainee teachers were related to the basic concepts of QM (quantum state and superposition principle, incompatibility, uncertainty), the design of educational paths on QM and monitoring tools (tutorials and questionnaires), and use of these tools both to activate a student-centered educational and inquiry-based environment, as well as to monitor their learning path (RQ3).

Teacher professional development in teaching–learning quantum mechanics requires a discussion of the fundamental concepts in the context of a specific research-based educational proposal, in which the trainee teacher must take on project and learning outcomes responsibilities with students. On this basis, the PCK of the teacher on the subject is built on the condition of putting in place a process that implies periodic reflections and discussions on fundamental elements of the PCK.

References

Am J Phys (2002) Special Issue on Quantum Mechanics, Am J Phys 70(3)

Asikainen M (2005) A study of students' learning processes on a new quantum physics course for pre-service and in-service teachers. In: Fischer H (ed) Developing standard in research in science education. Taylor & Francis, London, pp 55–62

Asikainen MA, Hirvonen PE (2009) A study of pre- and in-service physics teachers' understanding of photoelectric phenomenon as part of the development of a research-based quantum physics course. Am J Phys 77:658–666

Borello L, Cuppari A, Greco M, Rinaudo G, Rovero G (2002) Il metodo della "somma dei cammini" di Feynman per l'introduzione della Meccanica Quantistica: una sperimentazione nella Scuola di Specializzazione per l'Insegnamento. La Fisica Nella Scuola XXXV(2 Suppl):125–131

Cataloglu E, Robinett RW (2002) Testing the development of student conceptual and visualization understanding in quantum mechanics. Am J Phys 70:238–251

Denzin N, Lincoln Y (2011) Handbook of qualitative research. SAGE Publications, Los Angeles. https://doi.org/10.2307/3121684

Duit R, Gropengieβer H, Kattmann U (2005) Toward science education research: the model of educational reconstruction. In: Fischer HE (ed) Developing standard in research in science education. Taylor, London, pp 1–9

Francaviglia M, Lorenzi M G, Michelini M, Santi L, Stefanel A (2012) Teachers facing conceptual nodes of quantum mechanics. Aplimat J Appl Math 5. http://www.archiv.aplimat.com/2012/Proceedings/New_trends_in_education/Francaviglia_Lorenzi_Michelini_etal_1.pdf

Ghirardi GC, Grassi R, Michelini M (1995) A fundamental concept in quantum theory: the superposition principle. In: Bernardini C, Tarsitani C, Vicentini M (eds) Thinking physics for teaching. Plenum, Aster, pp 329–334

Hara N, Bonk CJ, Angell C (2000) Content analysis of online discussion in an applied educational psychology course. Instr Sci 28:115–152

Henriksen EK, Bungum B, Angell C, Tellefsen CW, Frågåt T, Bøe MV (2014) Relativity, quantum physics and philosophy in the upper secondary curriculum: challenges, opportunities and proposed approaches. Phys Educ 49(6):678–684. https://doi.org/10.1088/0031-9120/49/6/678/meta

Justi RS, Souza VCA, Ferreira PFM (2005) Analogies for the atom: students' and teachers' (mis) understandings. In: Pinto R, Couso D (eds) Cresils. Esera, Barcelona. ISBN: 689-1129-1

Kohnle A (2015) Research-based interactive simulations to support quantum mechanics learning and teaching. In: Fazio C, Mineo RMS (eds) Teaching/learning physics: integrating research into practice. Proceedings of the GIREP-MPTL 2014 International Conference, Palermo, Italy, July 7–12, 2014. Università degli Studi di Palermo, Palermo, pp 29–40

Krijtenburg-Lewerissa K, Pol HJ, Brinkman A, van Joolingen WR (2019) Key topics for quantum mechanics at secondary schools: a Delphi study into expert opinions. Int J Sci Educ 41(3):349–366. https://doi.org/10.1080/09500693.2018.1550273

Leinonen R, Haaranen M, Kesonen M, Koponen M, Hirvonen PE, Asikainen MA (2020) Finnish graduated physics teachers' views about their teacher education program: the disparity between the needs and delivery. J Technol Sci Educ 10(1):101–116. https://doi.org/10.3926/jotse.820

Mason B, Debowska E, Arpornthip T, Girwidz R, Greczylo T, Kohnle A, Melder T, Michelini M, Santi L, Silva J (2015) Report and recommendations on multimedia materials for teaching and learning quantum physics. Il Nuovo Cimento 38(C):105–116

McIntyre DH (2012) Quantum mechanics. Pearson Education Inc., San Francisco

Michelini M, Ragazzon R, Santi L, Stefanel A (2004a) Implementing a formative module on quantum physics far pre-service teacher training. In: Michelini M (ed) Quality development in the teacher education and training. Forum, Udine, pp 429–435

Michelini M, Rossi PG, Stefanel A (2004b) The contribution of research in the initial teacher formation. In: Michelini M (ed) Quality development in the teacher education and training. Forum, Udine, pp 166–172

Michelini M (2008) Approaching the theory of quantum mechanics: the first steps towards a coherent synthesized interpretation with a supporting formalism. In: Jurdana-Sepic R, Lubinac V, Xuvic-Butonac M, Susac A (eds) Frontiers of physics education. Zlatni, Rijeka, pp 93–101

Michelini M (2020) Dialogue on primary, secondary and university pre-service teacher education in physics. In: Guisasola J., Zuza K. (eds) Research and innovation in physics education: two sides of the same coin. Challenges in physics education. Springer, Cham, pp 37–51. https://doi.org/10.1007/978-3-030-51182-1_3

Michelini M (2021) Innovation of curriculum and frontiers of fundamental physics in secondary school: research-based proposals. In: Burra GS, Carnicer J, Michelini M, Perea C (eds) Fundamental physics and physics education research. Springer, Cham, pp 101–116. ISBN 978-3-030-52923-9. https://doi.org/10.1007/978-3-030-52923-9

Michelini M, Stefanel A (2006) Hands-on sensors for the exploration of light polarization. In: Planinsic G, Mohoric A (eds) Informal learning and public understanding of physics. Girep, Ljubijana (SLO), pp 202–208

Michelini M, Stefanel A (2021) Approaches on T/L quantum physics from PER literature. In: Jarosievitz B, Sukosd C (eds) Teaching-learning contemporary physics, challenges in physics education. Springer, Cham, pp 3–17. https://doi.org/10.1007/978-3-030-78720-2_1

Michelini M, Ragazzon R, Santi L, Stefanel A (2000) Proposal for quantum physics in secondary school. Phys Educ 35(6):406–410

Michelini M, Santi L, Stefanel A (2008) Worksheets for pupils' involvement in learning quantum mechanics. In: Jurdana-Sepic R, Lubinac V, Xuvic-Butonac M, Susac A (eds) Frontiers of physics education. Zlatni, Rijeka, pp 102–111

Michelini M, Santi L, Stefanel A (2013a) La formación docente: un reto para la investigación. Revista Eureka sobre Enseñanza y Divulgación de las Ciencias 10(Núm. Extraordinario):846–870.

Michelini M, Fera G, Pugliese E, Santi L, Stefanel A, Vercellati S (2013b) A research based e-learning process for teacher formation on quantum mechanics. https://conference.pixel-online.net/conferences/npse2013/common/download/Paper_pdf/059-NTT02-FP-Michelini-NPSE2013.pdf

Michelini M, Santi L, Stefanel A (2016) JQM per affrontare nella scuola secondaria i fondamenti di meccanica quantistica. In: Proceedings of XXX Convegno Didamatica. ISBN: 9788898091447

Michelini M, Santi L, Stefanel A (2017) Research based proposals to build modern physics way of thinking in secondary students. In Király A, Tél T (eds) Teaching physics innovatively. Eötvös Loránd University, Budapest, pp 331–349. ISBN: 978-963-284-925-6

Olsen RV (2002) Introducing quantum mechanics in the upper secondary school: a study in Norway. Int J Sci Educ 24:565–574. https://doi.org/10.1080/09500690110073982

Phys Educ (2000) Special Issue on Quantum Physics, Phys Educ 35(6)

Pospiech G (2000a) A modern course in quantum physics for teacher education. In: Xingkai L, Kaihua Z (eds) Turning the challenge into opportunities. Guangxi Normal University Press, Guilin, pp 244–248

Pospiech G (2000b) Uncertainty and complementarity. Phys Educ 35(6):393–399. https://doi.org/10.1088/0031-9120/35/6/303

Pospiech G (2003) Philosophy and quantum mechanics in science teaching. Sci Educ 12:559–571. https://doi.org/10.1023/A:1025384115480

Pospiech G, Michelini M, Stefanel A, Santi L (2008) Central features of quantum theory in physics education. In: Jurdana-Sepic R, Lubinac V, Xuvic-Butonac M, Susac A (eds) Frontiers of physics Education. Zlatni, Rijeka, pp 85–87

Robertson E, Kohnle A (2010) Testing the development of student conceptual understanding of quantum mechanics. In: Raine D, Hurkett C, Rogers L (eds) Physics community and cooperation, vol. 1. Lulu, Leicester, pp. 261–273. ISBN: 978-1-4461-6219-4

Shulman S (1986) Those who understand: knowledge growth in teaching. Educ Res 5(2):4–14

Stadermann HKE, van den Berg E, Goedhart MJ (2019) Analysis of secondary school quantum physics curricula of 15 different countries. Phys Rev Phys Educ Res 15:010130. https://doi.org/10.1103/PhysRevPhysEducRes.15.010130

Stefanel A, Michelini M, Ragazzon R, Santi L (2004) Blended activity on quantum mechanics knots for preservice teachers. In: Melchova M et al (eds) Teaching and learning physics in new contexts. Girep, Ostrava, pp 206–208

Styer DF, Balkin MS, Becker KM et al (2002) Nine formulations of quantum mechanics. Am J Phys 70:288–297

Taber KS (2007) Classroom-based research and evidence-based practice: a guide for teachers. SAGE Publications, Los Angeles

Taylor EF (1998) The boundaries of nature: special & general relativity and quantum mechanics, a second course in physics: Edwin F. Taylor's acceptance speech for the 1998 Oersted medal presented by the American Association of Physics Teachers, 6 January 1998. Am J Phys 66:369–376. https://doi.org/10.1119/1.18875

The Design-Based Research Collective (2003) Educ Res 32(1):5–8

Wiley A (2004) A proposed measure of discussion activity in threaded discussion spaces v0.9. http://wiley.ed.usu.edu/docs/discussion09.pdf

Zollmann D (ed) (1999) Research on teaching and learning quantum mechanics. Papers presented at the Annual meetings NARST. Published at https://perg.phys.ksu.edu/papers/narst/

The Impact of a Two-Year In-service Teacher Training Programme on the Use of the Laboratory and Self-Efficacy Beliefs

Marta Carli and Ornella Pantano

Abstract In 2018 we started COLLABORA, an in-service teacher training programme based on the learning community approach, aimed at improving the use of the laboratory in the teaching of physics. Starting from the findings of the first year and from the emerging learning needs, in the second year the efforts of the community focussed on the design of teaching–learning sequences and their experimentation in the classroom. Micro-teaching and peer-observation activities were also introduced. In this contribution, we describe the programme and its impact on teachers' practice and on their self-efficacy in using practical work in their teaching. We also discuss the activities that were most effective in improving the teachers' self-efficacy. Finally, we discuss the strategy used for the programme and the elements that were more effective in supporting teachers' professional development.

1 Introduction

Using practical work effectively in the classroom is a key competence for physics teachers (Hofstein and Lunetta 2004). The laboratory plays a central role in the construction of scientific knowledge and the use of inquiry-based approaches to the teaching of physics has been recommended by several international documents (Rocard et al. 2007; National Academies Sciences, Engineering, and Medicine 2019). However, in practice the laboratory is often seen as an 'inconvenient' element, due to different reasons: it requires a deep awareness of both physics content and processes, together with a specific form of pedagogical content knowledge; laboratory facilities are often inappropriate or even lacking; a tension is perceived between the request to cover an extensive list of topics and the amount of time required by practical work; and finally, teachers often lack personal experience in the laboratory or have weaknesses in content knowledge and, on the other hand, professional development programmes rarely offer laboratory experiences that follow design principles derived

M. Carli (✉) · O. Pantano
Department of Physics and Astronomy, University of Padua, via Marzolo 8, 35131 Padua, Italy
e-mail: marta.carli.1@unipd.it

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_8

from research (Millar et al. 2010; Crawford et al. 2014; Nivalainen et al. 2010; National Research Council 2006).

Based on these considerations, in 2018 we started an in-service teacher training programme named *COLLABORA—A Community of Learners on Laboratory work*, aimed at improving this competence. We presented the design and implementation of the first year of programme in a previous publication (Carli and Pantano 2019). Here, after an overview of the first year and its main findings, we present the design and implementation of the second year and we discuss the results of the final evaluation of the programme in order to gain insights into the following research questions:

- RQ1. How did the programme impact the teachers' use of the laboratory and their self-efficacy about using practical work in the classroom?
- RQ2. What sources of self-efficacy were most effective for this teacher training programme?

2 Background: The Original COLLABORA Project

The COLLABORA programme started in 2018 and it was built on the five 'core features' for effective teacher training identified by Desimone (2009):

- Content focus.
- Opportunities for teachers to engage in active learning.
- Coherence between teachers' learning and their knowledge and beliefs.
- Sufficient duration.
- Collective participation of teachers from the same school or grade.

We enriched this framework by considering three aspects that have been emphasized by recent research in teacher education: self-efficacy beliefs, action research and the learning community.

Self-efficacy beliefs are a class of teachers' beliefs that can be understood as context-dependent judgements about being able to perform a particular task and obtain the desired outcomes (Bandura 1986, 1993, 1997). The improvement of self-efficacy beliefs has been used for the evaluation of professional development also in the context of STEM disciplines (Lotter et al. 2007, 2018; Seung et al. 2019).

Action research is a process where practitioners identify a problem relevant to their context, select the data they need to answer their research question, design modified classroom procedures, implement and document the activities, evaluate their project and draw conclusions. With this approach, practitioners are actively involved in their professional development, which makes their learning meaningful and situated (Gilbert et al. 2010).

Learning communities (Vangrieken et al. 2017) are not a new concept in adult learning; however, their effectiveness in promoting innovation in physics education has been re-discovered recently (Couso 2008; Lotter et al. 2014; Singer et al. 2011) and a positive synergy between action research and the learning community approach has been suggested (Laudonia et al. 2017; Mamlok-Naaman 2018; LINPILCARE 2021).

We worked on a specific content strand, ‘waves and their applications’ (core idea PS-4 of the *Framework for K-12 science education* (National Research Council 2012)) which is central in the physics curriculum. During the meetings, the participants analyzed and engaged with research-based activities, discussed disciplinary issues and the didactical reconstruction of the topics and faced issues such as the assessment of scientific abilities (Etkina et al. 2006) and the role of experiments in a teaching–learning sequence (in particular, we referred to the classification into ‘observational’, ‘testing’ and ‘application’ experiments by Etkina and colleagues (2002)). Participants were also asked to design their own laboratory activity and to experiment it in the classroom, according to an action research paradigm. Throughout the programme, we monitored the evolution of teachers’ self-efficacy beliefs through the Teaching Science as Inquiry (TSI) test (Smolleck et al. 2006), a research-validated instrument based on Bandura’s theory of self-efficacy (Bandura 1997).

The programme lasted one year, featuring 13 meetings from May 2018 to June 2019. The group was set up as a learning community that shared common goals, rules and style. The participants were 15 teachers from 11 upper secondary schools (students aged 14–19) in the Veneto region (northern Italy).

The main findings from the programme evaluation were:

- All the features mentioned above were important, particularly the learning community and action research.
- Improvements in self-efficacy were higher for those who successfully completed their action research plan.
- There was a need for even more opportunities for interaction and for stronger support in the planning phase.

Based on these findings and on the wish of the participants to maintain the community, we decided to continue the programme for one more year.

3 Design and Implementation of the Second year

For the design of the second year, we decided to add some activities and features which could address the formative needs emerged after the first year.

As described above, a relevant finding from the first year was that improvements in self-efficacy were correlated to the successful completion of an action research plan. We then decided to further strengthen this point by empowering the participants’ ability to design a teaching–learning sequence (TLS) according to the principles of inquiry-based learning; they should then experiment their TLS in the classroom. As a framework for planning, we chose the backward design approach (Wiggins and McTighe 2006) since it resonated well with the emphasis on learning outcomes and their alignment with assessment that we had proposed during the first year. Finally, we made the planning phase longer and more collaborative: during the first two meetings, the teachers—divided in groups according to the topics they wanted to experiment on—reflected on the didactical reconstruction of the content and produced a common draft of their TLS, which they then completed individually. We also introduced micro-teaching sessions where one teacher proposed a segment of her/his draft TLS to the colleagues. This activity constituted a double opportunity for the group: the presenter received constructive feedback from her/his colleagues in order to improve her/his TLS before experimenting it in the classroom, while the colleagues could see an example of how one of their peers had drafted the TLS.

The second year of the programme started in October 2019 and ended in June 2020, featuring 9 monthly meetings. 11 of the 15 teachers who took part in the first year continued in the second year. The first two meetings were devoted to the planning of a research-based teaching–learning sequence (TLS) involving practical work. Teachers were grouped according to the topics they would like to experiment on. The backward design matrix was presented and each group of teachers worked together to fill in the first part of the matrix. After they had produced a common draft, each teacher completed his/her plan individually in order to tailor it to their real context.

From January 2020, the meetings were completely dedicated to micro-teaching and feedback, according to which the teachers should improve their draft TLS and then conduct the experimentation in the classroom. Two or three teachers proposed the micro-teaching during each meeting. However, from March 2020, due to the COVID-19 pandemic, we could not continue our face-to-face meetings, so we moved the meetings online. For each virtual session, one or two teachers presented his/her plan, including the challenges he/she had found in the adaptation for distance teaching and received feedback and advice. As teachers completed their experimentations, they also had the opportunity to present their results and discuss them with their peers.

As an example of the process, we briefly discuss here a TLS on interference and diffraction proposed by one of the teachers. The TLS was realized in a fourth-year classroom of high school between February and March 2020 and it was presented to the colleagues in the January meeting. The first part of the matrix—reported in Table 1—contains the desired 'understandings' and 'essential questions' according to the backward design logic and it was outlined together with another teacher as explained above. The second part of the matrix, containing the specific activities and the assessment strategy, was elaborated by the teacher individually and was modified after receiving feedback from colleagues and researchers. In Table 2 we report the activity part of both the original TLS and the modified TLS to highlight the effect of the feedback process.

One of the major changes—the introduction of an application experiment—was also related to the assessment of the TLS. In fact, the original TLS only featured a final test and a self-evaluation rubric, while the introduction of an 'authentic performance task' where the students apply their understandings to a new, real situation, seemed appropriate to ensure a more complete assessment in line with the desired understandings. The authentic task was evaluated using a specifically developed rubric, similar to the ones described by Etkina et al. (2006).

Table 1 Example of a TLS; first part of the backward design matrix

Understandings	Essential questions
(U1) The ray model explains some light phenomena (shadows, reflection, refraction), but not all of them. Some phenomena, such as the patterns observed when light passes through a small aperture, are explained by a wave model	(EQ1) What models can we use to explain light phenomena and what is their validity?
(U2) Since light is a wave, it is characterized by a velocity, a frequency and a wavelength, related through the wave equation. Light intensity is related to the amplitude of the wave, while colour is related to the wavelength of light. Interference and diffraction are observed as consequence of the interaction of light with itself or with objects	(EQ2) What are the consequences of modelling light as a wave? (What physical quantities are used to describe light and how are they related to our observations? What phenomenology do we expect?)
(U3) Interference and diffraction explain some everyday phenomena such as the colours of bubbles/of a CD and can be used in different technological applications	(EQ3) What are some everyday phenomena where we observe the wave nature of light?

The TLS was further modified for distance teaching as the school was closed due to the breakout of the COVID-19 pandemic. At the time, only the first three lessons (introductory lesson, observational experiment, post-lab session and conceptualization) had already been done. The application experiment was modified by dividing it into two phases: the *design* of an experiment to measure the thickness of a hair, identifying the relevant physical laws and models and describing the experimental setup; and the *solution* of the problem using data from a video experiment realized by the researcher. The TLS, its modification for distance teaching and its implementation are discussed in reference (Carli et al. 2021).

4 Programme Evaluation

Since the cohort was rather small, we decided to collect rich, qualitative data alongside quantitative data to evaluate the programme. We used four different instruments: an online individual survey, a focussed group interview, the Teaching Science as Inquiry test and individual interviews.

The online survey contained 10 questions. The first two questions were aimed at revealing changes in the teachers' practice, in terms of frequency of use of the laboratory and of the characteristics of the proposed laboratory activities.

The third and the fourth question investigated changes in self-efficacy; the first one asked whether the respondents felt more confident in the use of the laboratory at school with respect to the beginning of the programme, while the second one was aimed at identifying which of the 'types' of activities proposed during the two years

Table 2 Example of a TLS; 'activity' part of the backward design matrix. Both the original version and the modified version (after feedback) are reported

Original TLS	Modified TLS (after feedback)
Revision of ray optics phenomena + demonstration of interference (double-slit experiment) + introduction of wave model (2 h)	Students observe and revise some optical phenomena explainable with ray optics, they are asked to predict what happens when a laser beam passes through a slit. They then observe the phenomenon, facing the fact that they cannot explain the pattern using the ray model
'Testing' experiment: double-slit interference (2 h)	'Observational' experiment: students design and perform an experiment to investigate interference or diffraction and collect data to identify how each phenomenon depends on the variables they can control (slit width, distance from the screen, wavelength, …)
Post-lab session: discussion of the experiment; mathematical derivation of equations (2 h)	Post-lab session + conceptualization: students compare their results, which are interpreted using the wave model; interference/diffraction patterns are interpreted using wave superposition and Huygens principle; conditions for interference/diffraction and formulas for the position of maxima/minima are derived
'Observational' experiment: diffraction from a thin slit (1 h)	[included in the second lesson, see above]
Discussion of some applications of interference and diffraction (1 h)	'Application experiment': the students are asked to set up and carry out an experiment to find the thickness of a hair. Further examples of everyday phenomena that can be explained using the wave model of light are discussed

had been more effective in improving the participants' self-efficacy. Based on the literature (Bandura 1997; Palmer 2006) we identified six types of activities that could be considered as potential 'sources of self-efficacy':

- Planning and experimenting personally in the classroom with positive results.
- Listening to/experimenting positive experiences from my colleagues.
- Receiving positive feedback from my colleagues.
- Being in an environment where I felt encouraged, welcomed, supported and stimulated.
- Receiving information on the disciplinary content.
- Receiving information on the methodological/didactical aspects of science education.
- Being able to propose a TLS I had planned to my colleagues.

The fifth question investigated how the participants' competences in four areas (*understanding of physics content, understanding of experimental work, personal laboratory skills, ability in the design of laboratory activities, collaboration*) had improved during the programme, while the sixth question listed all the different kinds of activities that had been proposed during the programme (e.g. discussion of research-based activities, lessons on the use of the laboratory, small-group discussions, individual meetings with the researchers, …) and the teachers should indicate the extent to which they had found them useful.

The seventh and the eighth question probed the extent to which the programme adhered to the literature's recommendations about teachers' professional development, in particular to Desimone's 'core features' (Desimone 2009) (*content focus, active involvement, coherence with teachers' knowledge and beliefs, sufficient duration, collective participation*) and to Milner-Bolotin's *Model-Reflect-Research-Practice* approach (Milner-Bolotin 2018).

Finally, the ninth question investigated the role and the importance of the learning community and the tenth question explored the general satisfaction of the participant.

The semi-structured focussed group interview investigated five areas:

- The yearly programme (its strength and weaknesses, the extent to which the different activities were useful and/or challenging and how they could be improved).
- The learning community approach (its role, how it could be improved, its perspectives and future goals).
- The role of action research (how was the experimentation in the classroom, what methodologies and tools are needed).
- The dissemination of the programme (how we could share our experience with more colleagues, what instruments and strategies are needed).
- The features of effective in-service teacher training (what characteristics it should have and how we can make it sustainable).

Individual interviews were aimed at getting deeper insights into individual views and responses and into the participants' personal development during the course. They were divided in four sections:

- Impact of the programme (changes in the teacher's practice and in students' outcomes).
- Changes in self-efficacy (including a comment on the teacher's choices in question 4 of the online survey, concerning the types of activities that were more effective in this regard).
- Dissemination in/support from the school context (colleagues, headmaster).
- Overall evaluation of the programme (main learning outcomes, most relevant elements, remaining formative needs).

5 Results and Discussion

5.1 Impact on the Use of the Laboratory and on Self-Efficacy

Our first research question was: *How did the programme impact the teachers' use of the laboratory and their self-efficacy about using practical work in the classroom?*

All the participants stated that their use of the laboratory had changed through the programme. Reported changes regard:

- The quality of laboratory experiences: 'I have always given the students experiments that they had to follow step-by-step. Now I often give the students the opportunity to plan the experiment. Even when I give the students an experiment that is more like a 'cooking recipe', I see their approach has changed, because they know what's behind.' (E.P.)
- An increased attention to planning: 'I pay attention to the intermediate goals of each experience and not only to the final product.' (G.L.)
- An increased attention to assessment: 'One thing that I have introduced permanently in my practice is the use of specific assessment rubrics, which I always share with the students.' (L.G.)
- An increased confidence in their experimental skills: 'I feel more confident in handling the instruments. I no longer want the technician to lead the laboratory lessons.' (M.R.F.)
- An increased confidence in the management of laboratory lessons: 'I found it difficult to collect data and at the same time pay attention to the students' questions. Now when I am in the lab, I feel I can 'master' the situation.' (F.C.)

All the participants reported an improvement in self-efficacy, which was confirmed by the TSI test. Figure 1 reports box plots of the scores in the TSI test before and after the programme, divided into the two dimensions of Bandura's self-efficacy: personal self-efficacy (SE), i.e. the confidence in one's own ability to conduct an inquiry-based lesson and outcome expectancy (OE), i.e. the belief that the lesson will produce positive outcomes in the students. A net improvement was observed for the group. Interestingly, this improvement was greater for outcome expectancy (where a median improvement of +0.37 was obtained), meaning that the programme increased the teachers' confidence that their laboratory lessons can positively impact students' learning.

One of the teachers, L.G., who had the highest improvement in both personal self-efficacy (+1.17) and in outcome expectancy (+1.08), described her development as follows: 'When I started to teach physics, I had some ideas, for example, to get the students to work in groups and to make them plan their experiments. But my colleagues and some parents, too, put a lot of stakes on me, so my ideas were immediately undermined, as they said 'No, you have to show them [the students] the correct results, otherwise they won't understand'. This course helped me retrieve those ideas which I thought were right, but which I was abandoning and restructuring them properly. And previously the students' approach was, 'we have never done this

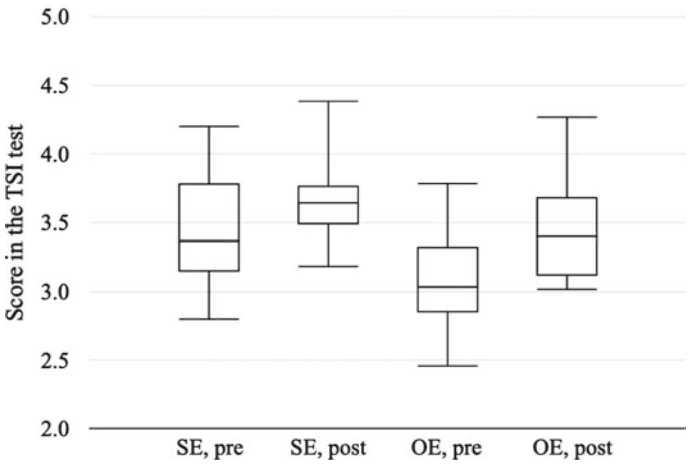


Fig. 1 Box plots of the pre/post scores in the TSI test, for the two dimensions 'personal self-efficacy (SE) and 'outcome expectancy' (OE)

sort of things'… and they were confused. But as my confidence increased, they accepted the change.'

5.2 *Sources of Self-Efficacy*

The second research question was: *What sources of self-efficacy are most effective for this teacher training programme?*

This research question was analyzed mainly with question 4 of the online survey, in which the teachers were asked to choose four out of six types of activities proposed during the course and to rank them from the most to the least important. During the individual interviews, we then asked the participants to comment on their choice, in order to understand why and in which way each source of self-efficacy was relevant.

To analyze these data, for each answer we assigned a score of 4 to the activity/source of self-efficacy ranked as the most important, 3 to the second one, 2 to the third one, 1 to the fourth one and 0 to the others. This way we calculated a total score for each source of self-efficacy. In Table 3 we report the six activities ranked in the order obtained by this scoring.

Listening to/experimenting with positive experiences from my colleagues' was evaluated as the most important source of self-efficacy; it was ranked as first or second by seven of the 11 participants. This statement refers to the micro-teaching/peer-observation activity that was introduced during the second year of the programme. During the individual interview, one teacher commented on his choice of this source of self-efficacy as follows: 'I was impressed by the quality of my colleagues' proposals. In a certain sense, this has a greater value than proposals from the

Table 3 The types of activities evaluated as more effective as sources of self-efficacy

Experience	Score
Listening to/experimenting with positive experiences from my colleagues	27
Receiving information on the methodological/didactical aspects of science education	21
Being in an environment where I felt encouraged, welcomed, supported and stimulated	19
Receiving positive feedback from my colleagues	13
Receiving information on the disciplinary content	10
Planning and experimenting personally in the classroom with positive results	8
Being able to propose a TLS I had planned to my colleagues	2

researchers, because they [the colleagues] use the language of teachers… Every time a colleague proposed an experience, I kept writing down notes and at home, I have folders with all their TLSs.' (E.P.).

The second most important source of self-efficacy according to the participants was 'receiving information on the methodological/didactical aspects of science education'. This result suggests that the support in terms of models for planning, reinforced during the second year, was in fact relevant.

On the third place, participants ranked 'being in an environment where I felt encouraged, welcomed, supported and stimulated', a condition that we created through the learning community approach. The relevance of this approach, which had already been highlighted at the end of the first year, was therefore confirmed also as a source of self-efficacy.

One teacher commented on these three choices as follows, highlighting how they are connected: 'Before the programme I had some good ideas, but they were not supported by evidence and most of all, the school environment did not encourage me. Knowing that my ideas are supported by research-validated models makes me more confident. However, this is not enough. Listening to experiences from my colleagues was crucial, because you may know a model, you may try to apply it and you may think you are doing right, but… if nobody does the same… whereas if I see others experimenting in the same way, I'll gain more confidence and also new ideas. Then [the environment] was important because ok, I can study the models, I can see that the others are trying them too, but then I need an environment that supports my experimentation; a place where all the problems and difficulties that arise—because they do—can be reported, faced, elaborated, otherwise I would give up at the first hurdle.' (L.G.).

5.3 *Final Reflections on the Programme*

Teachers' interviews provide insights into the strengths and weaknesses of the strategy used for professional development and help outlining some perspectives for the future.

The feature that was most cited as the most important one for the programme was the learning community. In the focus group, the community approach was defined ‘crucial’ for the effectiveness of the programme: ‘The community is formative. Teachers have a wealth of knowledge, experiences and things that they can do well, but we never share these things and we don’t find an environment that facilitates this sharing. This is a resource that is often wasted in schools. On the contrary, I think that professional development occurs when I prepare myself to train others and, by doing this, I also train myself […] But this training works in a community, where you know and trust one another and where you have time to think about it.’ (L.G); ‘What I did in the classroom was the result of what the group gave me; the work was not only mine, but it was also everyone’s.’ (M.R.F.).

The community was also the main reason for the stability of the group during lockdown: ‘Why I decided to stay? Because it is a community: the community dimension makes you stay. It is a group where I recognize myself and I feel comfortable, where I can perhaps bring something and where I definitely get a lot from the others.’ (F.M.); ‘When you go through a difficult time, you tend to retreat to the usual things; instead, being in the group set me in motion, gave me inspiration, the motivation to imagine something new.’ (M.P.).

Action research and micro-teaching activities were also judged important and a catalyzer for change: ‘In most training courses where there is a practical part, one wrong thing is that you always ‘pretend’: you imagine to be in a classroom and you try proposing something. But if you don’t really try in a real classroom, with a coach who gives you feedback and advice, if you don’t have time to think; if you cannot ask questions after you have tried and discuss how it went, it is not useful. Maybe you even try it in your classroom, but you stop there.’ (L.G.); ‘We as teachers ask ourselves every day if we are doing well or if we need to change; Participating in this group brings out this element, it drives you to find alternatives.’ (F.C.).

6 Conclusions

We have described a two-year in-service teacher training programme aimed at improving their competences in effectively using practical work in physics education. In this paper, we have focussed mainly on how the programme impacted the participants’ practice and their self-efficacy beliefs and on what sources of self-efficacy—corresponding to different strategies and activities proposed during the programme—were most effective.

Our results suggest that the impact was significant, most of all in terms of the quality of the proposed laboratory experiences and of self-efficacy in proposing practical work at school. The highest improvement concerned the participants’ expectations towards their students’ learning outcomes. Among the sources of self-efficacy, the opportunity of interacting with peers and observing how they planned and conducted laboratory activities were the most relevant ones but also support in the planning phase was needed and appreciated. The learning community, which gives the name to our project and which was our formative approach since the beginning, has been repeatedly highlighted as a very relevant factor: as a source of self-efficacy, but also as a collaborative, positive and encouraging environment for teachers thirst for.

We identify two major limitations in our approach: it is time-consuming and it works well with a limited number of teachers. Though these are not necessarily drawbacks in themselves, a question arises about how to scale up and keep it sustainable. The participants suggested maintaining the existing learning community and gradually enlarging it with new people. Once a 'critical mass' is reached at the local level, new learning communities may start, with the more experienced teachers acting as tutors of the new ones.

Acknowledgements We acknowledge the Scientific Degree Plan (Piano Lauree Scientifiche) of the Italian Ministry of Education, University and Research.

References

Bandura A (1986) Social foundations of thought and action: a social cognitive theory. Prentice-Hall, Englewood Cliffs

Bandura A (1993) Perceived self-efficacy in cognitive development and functioning. Educational Psychologist 28:117–148. https://doi.org/10.1207/s15326985ep2802_3

Bandura A (1997) Self-efficacy: the exercise of control. W H Freeman and Company, New York

Carli M, Fontolan MR, Pantano O (2021) Teaching optics as inquiry under lockdown: how we transformed a teaching-learning sequence from face-to-face to distance teaching. Phys Educ 56:025010. https://doi.org/10.1088/1361-6552/abcca7

Carli M, Pantano O (2019) Using practical work effectively in the school science laboratory: a teacher training programme based on the learning community approach. In: Levrini O, Tasquier G (eds) Electronic proceedings of the ESERA 2019 conference. The beauty and pleasure of understanding: engaging with contemporary challenges through science education. Alma Mater Studiorum-University of Bologna, Bologna, pp 1638–1647. https://www.esera.org/publications/esera-conference-proceedings/esera-2019

Couso D (2008) Authentic collaboration: a promising paradigm for physics education reform. Int Newslett Phys Educ (ICPE, IUPAP) 56:7–9. Retrieved from: https://web.phys.ksu.edu/ICPE/Newsletters/n56.pdf

Crawford BA (2014) From inquiry to scientific practices in the science classroom. In: Lederman NG, Abell SK (eds) Handbook of research on science education. Routledge, Abindgon, pp 515–541

Desimone LM (2009) Improving impact studies of teachers' professional development: toward better conceptualizations and measures. Educ Res 38:181–199. https://doi.org/10.3102/0013189X08331140

Etkina E, Van Heuvelen A, Brookes DT, Mills D (2002) Role of experiments in physics instruction—a process approach. Phys Teacher 40:351–355. https://doi.org/10.1119/1.1511592

Etkina E, Van Heuvelen A, White-Brahmia S, Brookes DT, Gentile M, Murthy S, Rosengrant D, Warren A (2006) Scientific abilities and their assessment. Phys Rev Special Topics-Phys Educ Res 2:020103. https://doi.org/10.1103/PhysRevSTPER.2.020103

Gilbert JK (2010) Supporting the development of effective science teachers. In: Osborne J, Dillon J (eds) Good practice in science teaching: what research has to say, 2nd edn. Open University Press, Maidenhead, pp 274–300

Hofstein A, Lunetta VN (2004) The laboratory in science education: foundations for the twenty-first century. Sci Educ 88:28–54. https://doi.org/10.1002/sce.10106

Laudonia I, Mamlok-Naaman R, Abels S, Eilks I (2017) Action research in science education—an analytical review of the literature. Educ Action Res 26:480–495. https://doi.org/10.1080/09650792.2017.1358198

LINPILCARE (LINk Practitioner Inquiry via effective Professional Learning Communities with the results of Academic Research) homepage. http://www.linpilcare.eu. Last accessed 08 Feb 2021

Lotter C, Harwood H, Bonner J (2007) The influence of core teaching conceptions on teachers' use of inquiry teaching practices. J Res Sci Teach 44:1318–1347. https://doi.org/10.1002/tea.20191

Lotter C, Thompson S, Dickenson TD, Smiley WF, Blue G, Rea M (2018) The Impact of a Practice-Teaching Professional Development Model on Teachers' Inquiry Instruction and Inquiry Efficacy Beliefs. Int J Sci Educ 16:255–273. https://doi.org/10.1080/09500693.2016.1259535

Lotter C, Yow JA, Peters TT (2014) Building a community of practice around inquiry instruction through a professional development program. Int J Sci Math Educ 12:1–23. https://doi.org/10.1007/s10763-012-9391-7

Mamlok-Naaman R (2018) Using the action research rationale to enhance the creation of teachers' professional learning communities (PLCs). ARISE J Action Res Innov Sci Educ 1:27–32. https://doi.org/10.12973/arise/94201

Millar R (2010) Practical work. In: Osborne J, Dillon J (eds) Good practice in science teaching: what research has to say, 2nd edn. Open University Press, Maidenhead, pp 108–134

Milner-Bolotin M (2018) Evidence-based research in STEM teacher education: from theory to practice. Front Educ 3:92. https://doi.org/10.3389/feduc.2018.00092

National Academies of Sciences, Engineering, and Medicine (2019) Science and engineering for grades 6–12: investigation and design at the center. The National Academies Press, Washington, DC

National Research Council (2006) America's lab report: investigations in high school science. The National Academies Press, Washington, DC

National Research Council (2012) A framework for K-12 science education: practices, crosscutting concepts, and core ideas. The National Academies Press, Washington, DC

Nivalainen V, Asikainen MA, Sormunen K, Hirvonen PE (2010) Preservice and inservice teachers' challenges in the planning of practical work in physics. J Sci Teacher Educ 2:393–409. https://doi.org/10.1007/s10972-010-9186-z

Palmer DH (2006) Sources of self-efficacy in a science methods course for primary teacher education students. Res Sci Educ 36:337–353. https://doi.org/10.1007/s11165-005-9007-0

Rocard M, Csermely P, Jorde D, Lenzen D, Walberg-Henriksson H, Hemmo V (2007) Science education now. A renewed pedagogy for the future of Europe. Office for Official Publications of the European Communities, Luxembourg. Retrieved from: https://www.eesc.europa.eu/resources/docs/rapportrocardfinal.pdf

Seung E, Park S, Lee M-A (2019) The impact of a summer camp-based science methods course on preservice teachers' self-efficacy in teaching science as inquiry. J Sci Teacher Educ 30:1–18. https://doi.org/10.1080/1046560X.2019.1635848

Singer J, Lotter C, Feller R, Gates H (2011) Exploring a model of situated professional development: impact on classroom practice. J Sci Teacher Educ 22:203–227. https://www.jstor.org/stable/43156598

Smolleck LD, Zembal-Saul C, Yoder EP (2006) The development and validation of an instrument to measure preservice teachers' self-efficacy in regard to the teaching of science as inquiry. J Sci Teacher Educ 17:137–163. https://doi.org/10.1007/s10972-006-9015-6

Vangrieken K, Meredith C, Packer T, Kindt E (2017) Teacher communities as a context for professional development: a systematic review. Teach Teach Educ 61:47–59. https://doi.org/10.1016/j.tate.2016.10.001

Wiggins G, McTighe J (2006) Understanding by design. Pearson, Merrill Prentice Hall

Lesson Study in Physics Education to Improve Teachers' Professional Development

Roberto Capone, Maria Giuseppina Adesso, and Oriana Fiore

Abstract This paper focuses on Physics in-service teacher training through Lesson Study—a widespread professional development practice with origins in Japanese elementary education, but which is now very popular worldwide, even in the West. The Lesson Study experimentation that we will describe was carried out in a scientific high school in Campania, in the south of Italy, and involved 14-year-old students, physics and mathematics teachers, and researchers from the University of Salerno. The Lesson Study cycle, subdivided into five steps (co-planning, teaching, observation, data analysis, and revision), focused on the interdisciplinary topic: climate change.

1 Introduction

In recent years, in-service teachers' professional development has acquired a central position in the Italian debate on educational policies, including international ones. Professional development interventions can only be based on teachers' needs and should offer tools and opportunities to investigate situations while involving teachers in activities structured to encourage them to break out of routinized practices and move toward the re-elaboration and re-planning of their teaching (Brophy 2006). Teachers agree that in-service professional development is the driving force of innovation (Vermunt et al. 2019; Capone et al. 2018; Weber et al. 2018), and the teaching–learning processes cannot remain static.

R. Capone (✉)
Department of Mathematics, University of Bari Aldo Moro, Orabona Street, Bari, Italy
e-mail: rcapone@unisa.it

M. G. Adesso
"Da Procida" High School, de Falco Gaetano Street, 2, 84126 Salerno, Italy

O. Fiore
Medicine and Surgery Department, University of Salerno, Giovanni Paolo II Street, 84084 Fisciano, SA, Italy

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_9

Among the various models that aim to develop teachers' professionalism and combine good effectiveness with sustainability and collaboration, the Japanese 授業研究 (*Jugyokenkyu*), known in the Western world as Lesson Study (Yoshida 1999), stands out.

It originated in Japan around 1870 to answer professional development needs for qualified teachers (Isoda et al. 2007). Lesson Study was introduced in the United States thanks to Catherine Lewis' research (Lewis 2000) and Makoto Yoshida's doctoral thesis (Yoshida 1999), creating an Anglo-American tradition. Following the TIMSS Video Study (Stigler and Hiebert 1999), Lesson Study (LS) gained the educators' and researchers' interest worldwide, mainly thanks to the policies and practices that promote collaboration and cooperation between teachers. In fact, in the following years, it has also been introduced in the Netherlands, Italy, Spain, Portugal, Switzerland, Great Britain, Indonesia, and Malaysia, as well as in South America, South Africa, Australia, Canada, Hong Kong, Sweden, Thailand, Vietnam to mention a few research groups participating in the conferences organized by the World Association of Lesson Studies (WALS). Several researchers worldwide have identified changes in teachers' beliefs or disposition toward working and learning, their mathematics knowledge for teaching, and their teaching practices (Huang and Shimizu 2016). LS has been effectively used in teachers' training in the West and worldwide (Ono and Ferreira 2010).

Nevertheless, it is interesting to analyze how a methodology rooted in eastern history and culture can work and fit into the Western context, where teaching is essentially a personal issue. Teaching indications are generally provided by expert researchers from outside the school context.

This Lesson Study is in continuity with other Italian studies and the authors' contributions to WALS 2019 (Capone et al. 2019a) and ICMI Study 25 (Capone et al. 2020). Moreover, it is linked with further Italian research focused on mathematical topics (Bartolini Bussi and Ramploud 2018; Robutti et al. 2016).

This paper describes the first experience (as far as we know) of Physics in-service teacher training through Lesson Study in Italy, carried out with five teachers and three researchers in a scientific high school, involving 14-year-old students. The topic chosen by the LS planning group has been climate change. Experimenting with Lesson Study in High School could provide stimuli for designing a path in continuity with previous school levels, marked by gradual and progressive objectives that allow consolidating learning. Hence, the need to create a unified design so strongly linked to the design of Lesson Study of other school segments that goes far beyond the mere diachronic distribution of educational content and makes contamination of teaching methods belonging to one or another school level.

The conceptual framework of the experimentation is based on Cultural Transposition and Inquiry-Based Science Education. The research methodology is an embedded case study, qualitative and ideographic. Both unstructured interviews and the analysis of video and audio recordings have been used as tools.

To reach this aim, the research question is:

Q1. Can the Lesson Study be effective in High School in-service Physics teachers training and favor collaborative teaching?

2 Conceptual Framework

In this section, details are provided on Inquiry-Based Science Education (IBSE) which formed the basis for the planning and the teaching phase and for the analysis of the experimental data. We used the IBSE framework to make physics more challenging, relevant, and attractive for students and stimulate their development of creative thinking, problem-solving, and other higher cognitive skills.

Moreover, Cultural Transposition is also described to contextualize LS in Italian academic society.

2.1 Cultural Transposition

More than a translation and adaptation, we introduced LS through a transposition that considers cultural factors.

The Cultural Transposition framework is essential to correctly transpose (Mellone et al. 2019) Lesson Study into the Italian institutional context in order to study it deeply, to deconstruct it to understand better which components are rooted in the native culture, which ones need to be adapted to the Italian context and which components are maintained across cultures. Cultural Transposition is a process put in place by researchers of mathematics education, which, coming into contact with educational practices of other countries, deconstruct and rethink the educational intentionalities embedded in the culture of those teaching practices for rethinking to own ones (Mellone et al. 2019).

The Cultural Transposition framework (Mellone et al. 2019) studies the "*decentralization of the educational [and, in our case, teachers' professional development] practice through the contact with educational practices from other cultural contexts*" (ibid., p. 210). This would allow teachers and researchers to become more aware of the implicit reasons behind educational and research choices.

2.2 Inquiry-Based Science Education

The National Research Council (NRC) described inquiry as "*a set of related processes through which scientists and students ask questions about the natural world and investigate phenomena; in doing this, students gain knowledge and develop an understanding rich in concepts, principles, models and theories*" (National Research

Council 1996) The first studies on the inquiry and the method that is called IBSE (Inquiry-Based Science Education) are due to Rosalind Driver and date back to the 1970s and 1980s (Driver 1985). The IBSE course is based on some exact results of the teaching research that we summarize below:

- Understanding science is much more than knowledge of facts.
- Everyone, particularly the students, knows and structures the new knowledge by modifying and redefining the concepts already possessed and adding new ones to those already known and considered reliable.
- The social context is fundamental in the mediation of learning (Vygotsky 1978);
- Students must be builders aware of their learning.

During the IBSE lessons, the teacher tries to maintain an environment favorable to the survey, to research the students. The latter work in groups, ask questions, make observations and experiments, collect data, interpret them, make hypotheses, and draw conclusions based on their own data.

In other words, students must have the first-hand experience of the phenomena they are studying.

There are two fundamental reasons for this; the first is that we know from research that first-hand experience is the key to understanding concepts. The second is that students continually build their understanding of the world right from experiences.

IBSE methodology has been used through the 5E Model (Bybee 2014). Each phase has a specific function and contributes to the teacher's coherent instruction and the students' formulating a better understanding of scientific and technological knowledge, attitudes, and skills. Teachers involved their students in "re-discovering" natural phenomena in the world around them, these phases being strictly connected to scientific Galileo's method. Moreover, these phases reflect mental steps that not only scientists, but also ordinary citizens follow when they acquire new knowledge and a new skill by organizing data, planning hypotheses, and verifying solutions (Adesso et al. 2019).

First, instructors open a lesson with an activity or question meant to *engage* students, snag their interest, and offer the opportunity for them to share what they already know on the subject.

After to engage, comes to *explore*, in which students carry out hands-on activities. Through their experiments or other interactions with the material, they deepen their understanding of the content. Once they have explored, students attempt to *explain* what they have learned and experienced with help from the teacher—who only then explains concepts or terms encountered during exploration. From there, students *extend* their understanding, applying what they have learned to new situations to deepen their skills. In the final phase, students *evaluate*, reflect on, and provide evidence of their new understanding of the material.

3 Methodology

The research methodology is observational and interpretative, with the added value of video research, which has allowed us to go into the details of verbal codes (conversational exchanges, oral reflections), non-verbal, proxemic, and interactional. The video cases were recorded in order to encourage reflective processes with the support of experts and in the sharing and comparison with peers.

The case study was carried out with five teachers (three physics teachers, two physics and mathematics teachers), and three researchers from the University of Salerno. In the teaching phase, fifty 14-years-old students at a high school near Salerno have been involved.

4 Activities

Two cyclic models were used in this work: the cyclic model of the Lesson Study, taken up by Lewis and colleagues (Lewis et al. 2019), although slightly modified, and the cyclic model of the 5E (Bybee 2014) with which the teaching activity was carried out in the classroom. So, the heuristic approach is defined by cyclical pathways, both for students and teachers in training.

The LS cyclic model is characterized by five main phases, as shown in Fig. 1.

During the co-planning phase, the project group wrote the Lesson Plan, including a detailed description of the class and all the activities to be carried out during the lesson. For each activity, its description, the working methodology, the detailed timing, and the educational purposes have been planned.

Following Bussi and colleagues' (Bartolini Bussi and Ramploud 2018) works about Lesson Study, the project group organized the observation grid about teachers' behavior (what to observe and how to observe it) during the lesson.

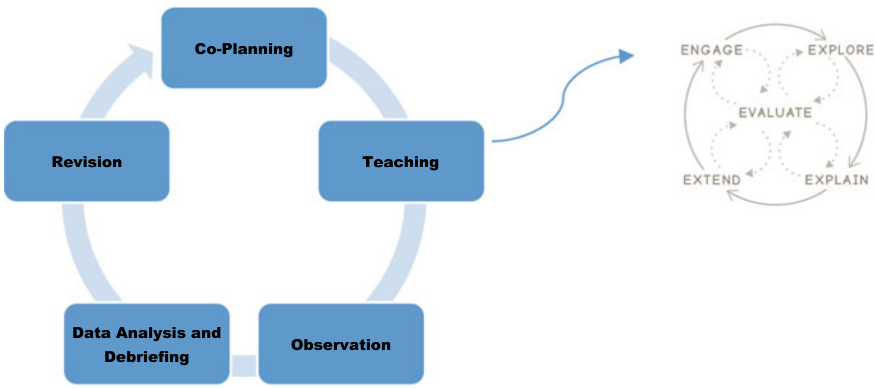


Fig. 1 Lesson study cyclic model, including IBSE cycle in the teaching phase

Table 1 Behavioral indicators for teachers in the observation grid

Categories	Behavioral indicators
Communication	✓ Does he/she provide students with all the essential elements for delivery? ✓ Does he/she provide explanations to the students during all the activities?
Interaction with the class	✓ Does he/she use gestures to support delivery understanding? ✓ Does he/she use gestures as teaching support?
Class management	✓ Does he/she participate in the student's activities? ✓ Does he/she intervene in student presentations?
Time management	✓ Does he/she manage the discussion times? ✓ Does he/she act in delivery times?

The observation grid is shown in Table 1.

The observers have used this grid during the teaching phase. Also, the researchers designed a questionnaire, used at the end of the debriefing phase, to analyze the impact of the Lesson Study on the teachers. All the materials and the resources necessary for the Lesson Study experimentation have been organized in this co-planning phase. The choice of materials to be used during the Lesson Study required careful planning because several factors were taken into account:

- the different learning styles of the students;
- the interest that the materials could raise in the students, trying to link the resolution of a mathematical problem to everyday reality;
- the link between the lesson and the students' whole educational path;
- consistency with specific students' learning objectives.

In order to choose LS activity, the teachers made a long-term design, also taking into account the national curriculum, organized through Learning Units. Among the topics envisaged for 14-years-old students, the learning unit "Measurement: quantities, numbers, and units" was chosen.

In Table 2, a diagram of the teaching unit divided according to knowledge and skills is given.

The topic chosen for the LS is included in this curricular design. In fact, in the teaching unit Measurement: quantities, numbers, and units, there is the Knowledge of Random errors and systematic errors. The lesson was focused on this topic using a real problem related to climate change.

Random errors and systematic errors are generally little understood by students because it is not related to their daily lives. Therefore, a topic for the LS has been chosen to provide students with a tool for understanding and interpreting reality through physics. Climate change is a real problem well embedded in error theory to verify an agreement between experimental data and theoretical models.

Teachers and researchers then decided to start the course with a one-hour Lesson Study segmented as reported below. Table 3 shows the details of the activities extracted from the Lesson Plan, structured according to the 5E model.

Table 2 Learning unit: measurement: quantities, numbers, and units

Knowledge	Skills
• Random errors and systematic errors	• Identify possible sources of error in the measurements
• The measurement of a physical magnitude and the uncertainty of a measurement • Absolute and relative uncertainty • Percentage uncertainty • Rules for calculating the uncertainties of derived quantities • Definition of significant digit • The characteristics of the instruments (sensitivity, range, readiness) • The different ways of representing experimental data (tables, histograms, Cartesian charts) • The interpolation line • Compatibility of two measures • Accuracy and accuracy of a measurement • The need to carry out independent experiments to validate a scientific discovery	• Measure a physical magnitude with the appropriate instrument • Determine the uncertainty associated with a measurement • Write the measure of a magnitude • Calculate absolute, relative, and percentage uncertainties • Calculate the average value, semidispersion, and standard deviation of a series of measures • Calculate the uncertainties of derived quantities • Approximate a measure to the correct number of significant digits • Represent experimental data (tables, Cartesian charts, histograms, etc.) • Represent the uncertainties of the measurements in the charts • Determine whether two measurements of a magnitude are compatible • Draw an easing line • Estimate the accuracy and accuracy of measurements • Experimentally verify a physical law

Table 3 Activities and times, as co-planned in the lesson plan

Heading	Description of the teacher's actions	Time (min)
Introduction	Students are presented with the topic by engaging	10
Presentation of the task	Students are presented with the problem of the day through experimental data collected by the teacher	15
Activity on the task in small group	Students work on the problem of the day (explore phase)	15
Students Presentation/explanation	Explain phase: One student per group exposes their solution to the problem of the day	10
Teacher's actions and interventions	The teacher guides the students in the discussion from which the students' skills emerge. The teacher assigns homework	10

After the co-planning phase, the teaching and observation phases followed. The 1st teaching was carried out by the pilot teacher and observed by one teacher and two researchers of the project group; each one filled the observations grid. In the data analysis and debriefing phase, each project group component analyzed the recorded videos and the components which were not observers filled their own observations grids. The lesson is focused on "climate changes": the importance of the climate change issue stems from the impact of changes in climate on human and natural systems; some consequences of climate change are an increase in global-mean temperature and a rise in sea level. In the LS, students have analyzed how the study of physics can help them understand these phenomena.

The teaching phase followed the inquiry model of the 5E, as described in detail below.

Step 1. *Engage*

In order to attract the attention of the deaf, two images were proposed to them to comment on, reading a poem on climate change, and listening to a piece of music.

Step 2. *Explore (The daily problem)*

To make students understand that physics studied in school helps us understand reality, a daily problem has been introduced where a graph of temperature as a function of time has been requested by using real data. The physical interpretation of these graphs allows for arguing about climate change. Pictured in Fig. 2 is the daily problem delivered to students.

Look at the graph in the picture: it shows the change in temperature in January, from the year 2010 to the year 2020, in a city in southern Italy. What are you looking at?
Calculates the average temperature and error of each statistical series. Compare the data to each other.
Are there significant variations over the years?

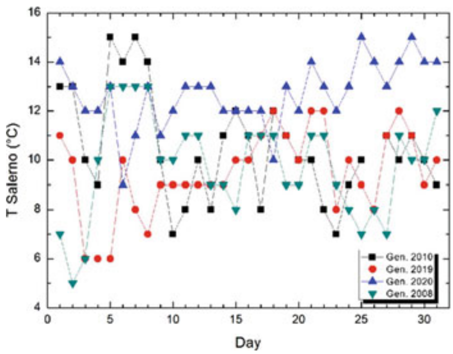


Fig. 2 Daily problem in the teaching phase

Step 3. *Explain*

During this phase, students are asked to find the link between observed charts, calculated parameters, and climate change.

Step 4. *Extend*

Situation learning:

Go to the Meteo.it, choose *a city. Look at the charts of temperature changes over the years. Build the corresponding chart.*

Step 5. *Evaluate*

Students show graphs and their empirical deductions. The teacher guides students to the formalization of the topic relationships between quantities, measurements, and errors.

The same lesson was then repeated (after refining it) in two other classes.

The lesson has been video recorded (1h30'). All project group components have analyzed the video. After two weeks, the data analysis and debriefing phase took place. Teachers were invited to answer a questionnaire. Here, we show some teachers' answers. On the importance of choosing together the activities to be submitted to the students, Teacher A replied as follows:

> *The discussion between teachers in the choice of the activity was very important; in our teaching practices, it is essential to choose an excellent engagement to motivate students to study physics and mathematics and keep their attention during the lesson.*

Teacher B answered as follows to how useful it was to be able to discuss with researchers, both in the planning of activities and in the phase of carrying out activities in the classroom:

> *The researchers helped us think about our teaching choices; often, these choices are dictated by experience, but the understanding that there are theories of Physics Education research that support teaching practices has been an added value of Lesson Study.*

The importance of Lesson Study on teachers' professional development, a difference between teachers' beliefs in the planning and after the teaching/observation phases was observed. The teachers were initially skeptical toward the Lesson Study methodology: Teacher A stressed how difficult it is to plan all the topics of an entire school year in such detail. Teachers B and C claimed to find the Lesson Study methodology very far from their school context. Nevertheless, all three teachers were willing to experiment with Lesson Study. Their attitude changed during the experiment. As an example, teacher C wrote in the debriefing questionnaire:

> *During the experimental phases, we realized that collaborative work is productive. It has been very important that mathematics teachers could discuss the design of activities, but above all, it was an added value to be able to observe each other;*

our teaching practices will undoubtedly be enriched, and each one of us will bring a piece of the other colleagues in its practices in the own classrooms.

A discussion about the teaching phase was also carried out in the debriefing phase. It was observed that the lesson did not respect the planned time allocation, and some possible causes were analyzed. The attention was focused on the detailed planning of the activities. A revision phase was necessary. The Lesson Study cycle started again. A new teaching phase, with a different teacher, was carried out, and this time the lesson lasted as planned (59'). After all the three Lesson Study cycles, the teachers were asked if it would be helpful to invest in this methodology for teachers' professional development. Everyone agreed on LS efficacy, and they pointed out that the most important aspect of Lesson Study is the collaborative work.

5 Discussion and Conclusion

This Lesson Study was carried out within a learning unit on *measurement: quantities, numbers, and units* were conducted with researchers and with physics/mathematics and physics teachers, at an Italian high school. The planned and experimented activities were tested with 14-year-old students in the teaching phase. The lesson focused on the theme of "climate change". A teacher (pilot teacher) carried out the first lesson.

In this work, Lesson Study, as transposed in Italy, has been experienced for in-service teachers' professional development in the Italian cultural context, in a collaborative framework. Both the Cultural Transposition and the IBSE framework provided the conceptual framework for teachers' collaboration within their daily practices.

Specifically, Lesson Study favored collaborative teaching through a dialogic comparison within a practice community constituted by teachers and researchers. A peer-to-peer sharing of experiences has been carried out. Cooperative and collaborative activities helped teachers to rethink their way of teaching.

Cultural Transposition has contributed to the training of teachers because it has made them more aware of their educational actions in the light of the comparison with other cultural contexts. Teachers have realized that some aspects of educational activities in Italy have their roots in an established cultural tradition, which is sometimes taken for granted.

This study suggests that to promote LS in a different education system effectively, the subtleties of Cultural Transposition should be considered. For instance, cooperative learning is known and appreciated by Italian teachers but is not so common in the Confucian heritage culture (Phuong-Mai et al. 2005). Moreover, the scientific Galilean method represents one of the cultural elements in the Physics teaching in Italy.

Using the lesson's video, the teachers themselves reviewed their teaching, allowing for the rethinking about their proxemics, posture, and relationship with the students. The detailed co-planning of the hour of the lesson also favored better time planning. From the protocols, in the debriefing phase, we deduced that the teachers, although at first uncertain on the effectiveness of the Lesson Study, in the end, all agreed on its usefulness for their professional development, especially for the aspects of collaboration and cooperation, both in the planning and in the teaching phase.

This aspect, too, can be interpreted with the lens of Cultural Transposition. Often the teacher works alone and experiences this condition of isolation in his class as a frustration. In our perspective, contact with educational practices other than those of one's cultural context can increase teachers' awareness in defining the nature of their educational proposal (Mellone et al. 2020). Researchers, in light of the deconstructive process, inaugurate other interpretative keys concerning the teaching practice of their cultural context. So, the teachers, starting from the reflection on the processes of the meaning of others, reflect on their teaching, including things they had not previously thought about (Mellone et al. 2019).

They noted that the support of the researchers was a further advantage to acquiring a greater awareness of their teaching activities, also considering the results of research in Physics Education. Although having some initial doubts, all teachers attended this experience and affirmed that they want to repeat it. Focusing on the Lesson Study methodology has allowed us to closely study teachers' practices in collaborative contexts, highlighting how the collaborative dimension in teaching–learning practices is a possible key to a real teaching reform. Collaboration between teachers is an important part of teachers' professional development, together with the collaboration between the Academia and the school, an added value toward more informed teaching practices in the light of research results. The data from the experiments provided a new understanding of how to promote, design, and evaluate relevant professional development practices for mathematics teachers in High School. The results also provide further support for the applicability of Lesson Study in our teaching practices (Capone et al. 2019b, 2021).

To summarize, the added value of Lesson Study in teacher training processes is:

(1) It is based on constructivism rather than on a transmission-oriented model.
(2) It is perceived as a long-term process.
(3) It is conceived as a cooperative and collaborative process.
(4) It is integrated into the curricular teaching activities.

References

Adesso MG, Capone R, Del Sorbo MR, Fiore O (2019, August) Light the world and change its color: a case study in Italian secondary school using IBSE methodology. J Phys Conf Ser 1286(1):012033. IOP Publishing

Bartolini Bussi MG, Ramploud A (2018) Il lesson study per la formazione degli insegnanti. Carocci, Roma

Brophy J (2006) History of research on classroom management. Handbook of classroom management: research, practice, and contemporary issues, pp 17–43

Bybee RW (2014) The BSCS 5E instructional model: Personal reflections and contemporary implications. Sci Child 51(8):10–13
Capone R, Del Regno F, Tortoriello F (2018) E-Teaching in mathematics education: The teacher's role in online discussion. J e-Learning Knowl Soc 14(3)
Capone R, Manolino C, Minisola R (2019a) Polyphony on Lesson Study in the Italian Context. In: WALS2019a
Capone R, De Luca R, De Santis A, Faella O, Fiore O, Saggese A (2019b) Training teachers: explorative activities measuring Planck's constant. J Phys: Conf Ser 1286:012046
Capone R, Manolino C, Minisola R (2020) Networking of theories for a multifaceted understanding on lesson study in the Italian context. In: Borko H, Potari D (eds) ICMI study 25 conference: teachers of mathematics working and learning in collaborative groups 2020b, pp 102–109
Capone R, Adesso MG, Del Regno F, Lombardi L, Tortoriello FS (2021) Mathematical competencies: a case study on semiotic systems and argumentation in an Italian High School. Int J Math Educ Sci Technolo 52(6):896–911. https://doi.org/10.1080/0020739X.2020.1726517
Driver R (1985) The pupil as scientist? Open University Press
Huang R, Shimizu Y (2016) Improving teaching, developing teachers and teacher educators, and linking theory and practice through lesson study in mathematics: an international perspective. ZDM Math Educ 48(4):393–409
Isoda M, Stephens M, Ohara Y, Miyakawa T (2007) Japanese lesson study in mathematics: its impact, diversity and potential for educational improvement. World Scientific Publishing, Singapore
Lewis C (2000) Lesson study: the core of Japanese professional development. Paper presented at the American educational research association annual meeting 2000; New Orleans
Lewis C, Friedkin S, Emerson K, Henn L, Goldsmith L (2019) How does lesson study work? Toward a theory of lesson study process and impact. In: Huang R, Takahashi A, da Ponte JP (eds) Theory and practice of lesson study in mathematics. Springer, pp 13–37
Mellone M, Ramploud A, Di Paola B, Martignone F (2019) Cultural transposition: Italian didactic experiences inspired by Chinese and Russian perspectives on whole number arithmetic. ZDM Math Educ 51(1):199–212
Mellone M, Ramploud A, Carotenuto G (2020) An experience of cultural transposition of the El'konin-Davydov curriculum. Educational studies in mathematics. Springer, pp 1–18
National Research Council (1996) National science education standards. National Academies Press
Ono Y, Ferreira J (2010) A case study of continuing teacher professional development through lesson study in South Africa. S Afr J Educ 30(1)
Phuong-Mai N, Terlouw C, Pilot A (2005) Cooperative learning versus Confucian heritage culture's collectivism: confrontation to reveal some cultural conflicts and mismatch. Asia Eur J 3:403–419
Robutti O, Cusi A, Clark-Wilson A, Jaworski B, Chapman O, Esteley C, Joubert M (2016) ICME international survey on teachers working and learning through collaboration: June 2016. ZDM Math Educ 48(5):651–690
Stigler JW, Hiebert J (1999) The teaching gap. Free Press, New York
Vermunt JD, Vrikki M, van Halem N, Warwick P, Mercer N (2019) The impact of lesson study professional development on the quality of teacher learning. Teach Teach Educ 81:61–73
Vygotsky LS (1978) Internalization of higher psychological process. In: Cole M, John-Steiner V, Scribner S, Souberman E (eds) Mind in society. The development of higher psychological process. Harvard University Press, Cambridge, London, England, pp 52–57
Weber KE, Gold B, Prilop CN, Kleinknecht M (2018) Promoting pre-service teachers' professional vision of classroom management during practical school training: effects of a structured online- and video-based self-reflection and feedback intervention. Teach Teach Educ 76:39–49
Yoshida M (1999) Lesson study: a case study of a Japanese approach to improving instruction through school-based teacher development (Doctoral dissertation). University of Chicago

What Do Novice Physics Teachers Identify as Their Problems of Practice?

Deirdre O'Neill and Eilish McLoughlin

Abstract Novice teachers, starting their teaching careers, face a range of challenges related to implementing pedagogical approaches, building relationships and transitioning into a new educational environment. This study examines the experiences of seven novice physics teachers transitioning from pre-service teacher education to in-service teaching. The focus of this study is to identify novice teachers' problems of practice, teaching secondary physics, as a first step to fostering a research-practice partnership between the teachers and physics education researchers. Findings from one-to-one interviews identified the problems of practice highlighted by the teachers and provides an in-depth understanding of their specific needs at the start of their physics teaching career. This study highlights the specific needs of novice physics teachers that should be addressed in designing professional learning opportunities.

1 Introduction

One of the most common issues novice teachers face in the transition from their initial teacher education programme into their early years of teaching is that they are not fully prepared for the complex situations they are faced with, when they enter the classroom (Niemi 2002). Prior to this, novice teachers are mostly 'participants in their learning' which is a compulsory part of their course demands (Smith and Sela 2005) and during their pre-service teacher education, they struggle with how to appropriately plan for teaching. Etkina outlines some of the issues pre-service physics teachers face in planning lessons which include, underestimating the time needed to teach a concept, planning logical lesson progression, gaps present in their own content knowledge, difficulty relating content to curricula and assessment practices (Etkina 2010). When these teachers begin their teaching career as novice teachers, they are faced with some persistent problems of practice and other new challenges. Novice teachers' lack of anecdotal experience of difficulties that arise in the physics

D. O'Neill (✉) · E. McLoughlin
CASTeL, School of Physical Sciences, Dublin City University, Dublin, Ireland
e-mail: Deirdre.oneill49@mail.dcu.ie

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_10

classroom is unanticipated and this can have an impact on their transition to in-service teaching (Goodman et al. 2006). Novice teachers face difficulty in separating their experiences of being taught from learning how to teach (Goodman et al. 2006). Literature reports that novice teachers often revert back to traditional methods of teaching based on their own experiences as a learner (Hopper 1999; Kennedy 1999; O'Meara et al. 2017). There are many reasons for this regression, such as translating content knowledge into learning opportunities, classroom management and supporting student learning, which becomes especially challenging for newly qualified teachers that are teaching outside of their subject specialism (Napier et al. 2020). The induction period of teaching can often undermine pre-service teacher preparation due to its chaotic nature and absence of support and lead to teachers focussing on instructional strategies to control student behaviour rather than on student learning (Evertson et al. 1985).

There is a need to create supportive teaching communities as an effective strategy to support teacher professional learning at all career stages. Examples of teaching communities such as professional learning communities and communities of practice are reported to support professional learning through collaboration, sharing and participating in learning activities with colleagues (Vangrieken et al. 2017). The model of a research practice partnership (RPP) centres on the premise that equal partners identify common goals and design joint exploration of a shared problem (Penuel and Gallagher 2017). Penuel insists that focussing on persistent problems of practice examined within the teachers' context of development and considering ecological resources and constraints is necessary to facilitate meaningful change in classroom practices (Gutiérrez and Penuel 2014). The aim of this study is to identify the needs of novice physics teachers so that appropriate strategies are used to design and facilitate professional learning opportunities. This study focuses on determining novice physics teachers' problems of practice at the start of their first year of teaching and investigates the following research question:

What do novice physics teachers identify as their problems of practice during their transition from pre-service to in-service teaching?

2 Methodology

The participants in this study were seven novice physics teachers. This group of novice teachers had just completed a four-year concurrent undergraduate programme leading directly to qualification as a physics teacher. The programme included four school placement periods over the four years, allowing pre-service teachers to develop the necessary pedagogical skills they will use in a real classroom environment. The longest school placement period took place in the final semester of fourth year, where pre-service teachers teach physics classes at lower and upper second levels.

Semi-structured one-to-one interviews were conducted online with each participant just after they completed their final school placement in May 2020. The interviews were approximately 45 minutes in duration and probed five key areas: stand-out experiences, challenges and how they were overcome, support available and needed, opportunities to collaborate with others, difficult physics concepts and barriers for students studying physics. Consideration was given to the challenges that interviewing in the online space would bring such as: access to reliable technology for both the researcher and participant, technological issues breaking the flow of conversation, establishing trust and rapport with participants (Weller 2017; Bampton and Cowton 2002).

Thematic analysis was chosen as the method of analysis for this study because of its flexibility to capture the complexities of meaning within qualitative data as reported in the literature (Braun and Clarke 2006; Guest et al. 2011). The interviews were transcribed and entered into QSR's NVivo software for qualitative data analysis. An inductive approach was taken in the analysis of the data whereby themes were identified in an inductive or bottom-up way and were strongly linked to the data as a result (Braun and Clarke 2006). The method of synthesis took the form of open coding of the primary evidence, organisation of these codes into descriptive themes and finally the development of analytical themes (Thomas and Harden 2008). These themes highlighted the problems of practice of novice teachers and formed the basis of the first task [formulating the joint 'problem'] of building an effective research-practice partnership (Penuel and Gallagher 2017).

3 Findings

Six themes were generated from the data collected from the interviews with novice teachers and these themes included 387 text references assigned to 125 codes. The themes were ordered by frequency of responses, namely: (i) content knowledge for teaching physics, (ii) managing myself, (iii) student learning, (iv) classroom management, (v) impact of COVID-19 and (vi) barriers to physics. Each of these six themes and related sub-themes is shown in Table 1 and discussed in the following sections.

3.1 Content Knowledge for Teaching Physics

Content knowledge for teaching physics was the most frequently referenced theme throughout teacher interviews, with 188 references attached to 46 codes. Teachers discussed a broad number of aspects associated with content knowledge for teaching physics such as: teaching approaches, preparation and planning, resources, content knowledge for physics, assessment and curriculum.

Table 1 Overview of themes from novice teacher interviews

Theme	Sub-themes
Content knowledge for teaching physics	Teaching approaches Preparation and planning Resources Content knowledge for physics Assessment Curriculum
Managing myself	Interactions with their colleagues New experiences as teachers Pre-service teacher preparation School structure
Student learning	Students' engagement and understanding Student expectations Student motivation
Classroom management	Strategies Issues encountered in the classroom Relationships with students
Impact of COVID-19	Online teaching and learning Student engagement
Barriers to physics	Numbers of physics teachers

Teachers discussed teaching approaches in great depth, considering how different learner types could be facilitated in the classroom and adapting their approaches to meet their students' needs. There was a tension for teachers between adapting new teaching approaches and reverting back to traditional teaching approaches that were advocated by some of their cooperating teachers. Making their teaching accessible to students was discussed by the teachers and they provided real-life examples and implemented student-centred learning activities in order to create engaging learning opportunities. However, teachers expressed their concern about spending too much time attending to students that were struggling to comprehend concepts. They found it difficult to balance their time between all students in a class and as a result began falling behind on pace. E.g., '*You try to not focus on the one group of kids but that's what would happen a lot where just one person was being focussed on and the rest were left to fend for themselves a bit.*'—P3

Preparation and planning consumed a large amount of these novice teachers' time. All of the participants reported having to learn the material themselves before teaching it and this included trying out experiments beforehand. One of the teachers described an experience where she did not have time to test the equipment beforehand and as a result, did not achieve the planned learning outcomes of the lesson. Teachers also reported that planning the sequencing of lessons and deciding on a suitable level to pitch the lessons as challenges in their lesson planning.

Six out of the seven teachers referred to resources in their interviews. Here, novice teachers discussed how power points, written notes, worksheets, digital resources (laptops, tablets, etc.) and videos aided their facilitation of lessons. The general consensus from these teachers was that the textbook was used for reference rather than as a resource for students. Teachers preferred creating their own resources and suggested that if they were to start their placement again that having their resources developed and organised beforehand would be a key focus for them. E.g., '*So, having all of them resources pre-made before you get to know your class will help and then as you get to know your class you can start making your own things…*'—P3

Within this theme, all of the novice teachers referred to specific content knowledge for teaching physics. Light and heat were the concepts that teachers identified as being the easiest to teach. Some teachers noted that they had just completed these topics as part of their pre-service teacher education and other teachers liked that there was a strong investigative element to these topics. Gravity, weight, magnetism, resonance and energy were some of the concepts that teachers experienced challenges in teaching due to their own depth of knowledge of the topic. The main challenge that they reported was dealing with difficult student questions that they felt they could not anticipate in their planning. E.g., '*This deeper knowledge is the knowledge that would help me to answer the many random questions posed by students that are related to the topics being discussed…*'—P6

Finally, assessment and the curriculum were also discussed by the novice teachers within this theme. Teachers discussed different methods of assessing students such as: questioning, assessment activities, student feedback (student questions about a topic), peer assessment and formative feedback. Teachers highlighted that assessing student understanding was sometimes inhibited by the focus on assessing for final exams. Knowledge of the curriculum was an area that novice teachers wanted to improve on during their placement. Experience of carrying out mandatory physics experiments was one of the specific elements of the curriculum that teachers said they would have liked to be more prepared for.

3.2 Managing Myself

The theme of managing myself was generated from the responses of all seven teachers. They discussed their interactions with their colleagues, new experiences as teachers, the relevance of their pre-service teacher preparation and how the school structure facilitated or inhibited their teaching experience. Support was a common idea that teachers referred to and they particularly valued the expertise of other teachers (both science and from other disciplines) who offered advice and guidance on areas such as student behaviour and accessing resources. Those teachers who felt unsupported by their cooperating teacher (N = 3), mostly reported a lack of communication in sharing resources, discussing teaching strategies and ideas and discussing student difficulties within the class.

Teachers described their autonomy as a newly qualified teacher. Naturally, they felt confined by their cooperating teacher's methods and the department plans as they were 'taking over' a class and still had to report back to the cooperating teacher. Confidence was reported to have improved as a result of teaching placement in nearly half of the cohort. However, all participants referenced one or more incidents that occurred, to threaten their confidence such as: being challenged by students, unsupportive cooperating teachers, lack of content knowledge, unmotivated students, losing classes as a result of moving to online teaching. Two of the participants expressed their concern about their suitability to the profession. E.g., '*I think I have a fear of students not understanding me or not liking the subject because I'm teaching it, not because they don't particularly have a like for the subject.*'—P7

Organisation and time management were one of the challenges that these novice teachers faced. They reported having little time left to themselves after planning lessons with differentiated tasks, searching for suitable resources, keeping up with a demanding timetable and brainstorming solutions to classroom management issues. E.g., '*…running from substituting three classes into a double science, you need to be prepared and be going in ready to take that class.*'—P1

3.3 Student Learning

The theme of student learning focussed on students' engagement and understanding, the expectations that novice teachers had of their students and student motivation. Student engagement was strongly linked to teacher preparation and the shift to online learning. Teachers reported students losing interest if an experiment didn't go to plan [due to not having tried it before the class]. They also referred to online learning as an opportunity for students to disengage with little consequence for not participating in lessons (discussed further in theme 3.5). Teachers felt that in order to facilitate student understanding, practical applications of the concept needed to be incorporated into their teaching strategies. This could take the form of demonstrations or analogies for abstract concepts. Assessing student understanding did not feature in teacher discussions and when probed on how they knew if their students were understanding a concept, one teacher said that 'you just know from their expressions'.

Most of the teachers overestimated the academic level of their students. They were surprised that students struggled to answer some of the questions that they posed and that applying knowledge did not come naturally to their students. This caused challenges in the teachers' planning and pacing of lessons. E.g., '*So, I had to change how quickly I was going through the content and my style of teaching as well and maybe lower my expectations of what they should be doing…*'—P7

Student motivation was discussed by the teachers in terms of student participation in class and student confidence where they would not complete a task if they found they would not be able to understand it. Student access to online devices and books was reported to be a major contributor to lack of student motivation as they found it difficult to engage with the class.

3.4 Classroom Management

This theme was reported by six out of the seven participants and mostly focussed on strategies, issues encountered in the classroom and relationships with students. Most of the strategies outlined by teachers were as a result of dealing with student behavioural issues in the class. These issues ranged from disruptive behaviour, noisy classroom environment, students that were completely disengaged and individual students that challenged the teachers in class. These novice teachers highlighted the power of observation in their first weeks out in the class and optimising the observation weeks to learn seating plans, students' names and the class teacher strategies for dealing with troublesome behaviour. Some teachers referred back to their pre-service teacher education for inspiration on some new techniques that could be employed. It was obvious from teacher discussion that they were using this time to try out different strategies to see what worked for them. E.g., '*And even everything that we learned about him in college in behavioural management, didn't work on him at all…*'—P3

The novice teachers also highlighted the importance of building relationships with their students that were both respectful and encouraged participation and engagement. They felt that getting to know their students was the first step to managing classroom behaviour.

3.5 Impact of COVID-19

In March 2019, the COVID-19 pandemic lockdown hit Ireland and at this point the novice teachers had completed approximately 8 weeks of teaching placement. With schools moving to online learning for the remainder of the term, teachers were faced with many challenges such as: adjusting to an online teaching and learning environment and dealing with student disengagement. There were mixed reports of experiences during this time. Asynchronous methods were used mostly and the teaching platforms used ranged from google classroom, to assigning homework through email communication. Teachers highlighted that there was little interaction with synchronous learning through live lessons and in the cases where this did occur, student attendance was very low (e.g. 1 out of 15 students). Two of the teachers lost all of their classes during this time as the cooperating teacher decided to take the responsibility of the classes back. They suggested this was because now students would have only one science class a week as opposed to three before the lockdown. Overall, the teachers noted that their schools were not prepared for the move to online learning and as a result their own engagement with online learning tools was minimal. E.g., '*I also think it [losing classes to online learning] happened to me as I had only one or two classes with each of my class groups for the week and their main teacher took the rest…I wasn't really in charge of any class group.*'—P4

Student engagement with online learning was also challenging for teachers. Teachers noticed that the students that usually volunteered answers in the physical classroom were the only students that engaged in online learning. For those students that did not reply to email correspondence, the novice teachers found it difficult to assess their understanding or differentiate for student needs. E.g., '*There was a couple who didn't really, they weren't able to answer some questions and, it's just very difficult to get back to them and gauge whether they understand it or not.*'—P7

3.6 Barriers to Physics

The theme of barriers to physics as a subject for students was probed by the interviewer and the responses were compiled to generate its own theme. Teachers did not differentiate physics from the other subjects they taught when speaking about possible barriers for students. Overall, they reported that students reacted better to concepts that they were able to see through demonstration or investigation. One teacher commented that she noticed in all of her placements that there was only one physics teacher in the school and this meant that it was difficult for a novice teacher coming into their class to try new ideas when teaching. E.g., '*So, it was, in every school I go into it's been very much like how that teacher runs his classes and just complies with that*.'—P5

4 Discussion

The findings from novice teachers' interviews highlight some of the problems of practice that arise after their classroom-based experience. Confidence in employing their own teaching approaches and having autonomy of their classes was a problem of practice identified by novice teachers in the theme of *Content Knowledge for Teaching Physics*. Student differentiation and planning and preparing to accommodate student needs were highlighted as another problem of practice. Teachers identified specific areas of physics content knowledge that they found challenging in their teaching such as: energy, waves, magnetism and gravity. Student learning, although described as a separate theme, also reflects novice teachers' lack of judgement of student understanding and assessing student understanding. These findings suggest that further cycles of sustained planning and implementation of plans focussed on student progress that intersect with teachers' tasks of teaching are necessary to enhance their content knowledge for teaching physics concepts (Etkina et al. 2018).

The theme of managing myself indicates the challenges teachers face as individuals in the transition from pre-service teachers to novice physics teachers. Here, it is evident that the teachers were experiencing a change in roles especially when they described some of their experiences as the learner and other experiences through the eyes of the teacher. Goodman et al., describe this as 'moving through' a transition and outline that this requires letting go of former roles and learning new roles (Goodman et al. 2006). The problems of practice associated with this theme reflect this shift when teachers discuss managing a work/life balance and needing more support from cooperating teachers.

The problems of practice associated with the theme of classroom management echo some of the issues reported by novice teachers in the literature. Although building relationships can be an engaging and rewarding experience of teaching, managing challenging relationships with students is a common problem that beginner teachers face that can lead to feelings of powerlessness (Hobson et al. 2007). The need for support through establishing teacher communities to share and discuss these issues of concern is necessary for teachers to reposition a seemingly negative event (such as a difficult incident with a student) and discover the positive potential to learn from the situation (Larrivee 2000).

Highlighting the issues teachers faced as a result of COVID-19, reiterates some of the persistent problems of practice faced by novice teachers such as: student engagement, assessing student understanding and teaching autonomy. However, the most significant impact that the pandemic had on novice teachers was the move to online learning and the problems associated with this. Chadwick and McLoughlin report that school closures had a somewhat negative impact on teachers' ability to support student learning, differentiate learning and make judgements on the progress of student learning all of which were concerns expressed by the novice teachers in this study (Chadwick and McLoughlin 2020).

The theme of barriers to physics did not reveal any obvious problems of practice aside from the observation that there are low numbers of physics teachers in schools. This may be due to the lack of experience of these novice teachers in recognising their students' barriers to learning physics. This could also be attributed to the fact that as novices they are not fully integrated into school culture and are still 'making sense' of the environment, to recognise a trend in student learning in one subject compared to another (Allen 2009).

5 Conclusion

This study highlighted the need for designing teacher professional learning experiences that focus on effective collaborative planning where teachers have similar goals based on real problems of practice (Penuel and Gallagher 2017). Findings from one-to-one interviews revealed the problems of practice that these novice teachers identify at the start of their teaching career and highlighted their specific needs for professional learning. The findings from this study identified that both teacher and student learning must be intersected in the design, implementation and refinement of classroom planning (Etkina et al. 2018). This study suggests that creating opportunities for novice teachers to reflect on their practice and have confidence in their own teaching approaches to promote student understanding could be enhanced through research practice partnerships. The identification of these problems of practice is a critical first step in designing effective professional learning opportunities. RPPs can become a suitable strategy for facilitating meaningful professional learning focussed on teachers' specific needs through their methods of establishing meeting processes, negotiating problems of practice and implementing initiatives that build on cultures of evidence-based practice (Penuel and Gallagher 2017).

References

Allen JM (2009) Valuing practice over theory: how beginning teachers re-orient their practice in the transition from the university to the workplace. Teach Teach Educ 25(5):647–654. https://doi.org/10.1016/j.tate.2008.11.011

Bampton R, Cowton CJ (2002) The e-interview. In: Forum qualitative Sozialforschung/forum: qualitative social research

Braun V, Clarke V (2006) Using thematic analysis in psychology. Qual Res in Psychol 3(2):77–101. https://doi.org/10.1191/1478088706qp063oa

Chadwick R, McLoughlin E (2020). Impact of the COVID-19 crisis on science teaching and facilitation of practical activities in Irish Schools. Irish Educ Stud 40(2). https://doi.org/10.1080/03323315.2021.1915838

Etkina E (2010) Pedagogical content knowledge and preparation of high school physics teachers. Phys Rev Spec Top-Phys Educ Res 6(2):020110. https://doi.org/10.1103/PhysRevPhysEducRes.14.010127

Etkina E, Gitomer D, Iaconangelo C, Phelps G, Seeley L, Vokos S (2018) Design of an assessment to probe teachers' content knowledge for teaching: an example from energy in high school physics. Phys Rev Phys Educ Res 14(1):010127. https://doi.org/10.1103/PhysRevPhysEducRes.14.010127

Evertson CM, Hawley WD, Zlotnik M (1985) Making a difference in educational quality through teacher education. J Teach Educ 36(3):2–12. https://doi.org/10.1177/002248718503600302

Goodman J, Schlossberg NK, Anderson ML (2006) Counselling adults in transition: linking practice with theory. Springer Publishing Co.

Guest G, MacQueen KM, Namey EE (2011) Applied thematic analysis. Sage Publications

Gutiérrez KD, Penuel WR (2014) Relevance to practice as a criterion for rigor. Educ Res 43(1):19–23. https://doi.org/10.3102/0013189X13520289

Hobson AJ, Malderez A, Tracey L, Homer M, Mitchell N, Biddulph M et al (2007) Newly qualified teachers' experiences of their first year of teaching. Findings from Phase III of the becoming a teacher project. Available from: https://dera.ioe.ac.uk/7908/1/DCSF-RR008.pdf

Hopper T (1999) The grid: reflecting from preservice teachers' experiences of being taught. J Phys Educ, Recreation Dance 70(7):53–59

Kennedy MM (1999) The role of preservice teacher education. Teaching as the learning profession: Handbook of policy and practice, pp 54–85. Available from: https://www.researchgate.net/publication/268053312

Larrivee B (2000) Transforming teaching practice: becoming the critically reflective teacher. Reflective Pract 1(3):293–307. https://doi.org/10.1080/713693162

Napier JB, Luft JA, Singh H (2020) In the classrooms of newly hired secondary science teachers: the consequences of teaching in-field or out-of-field. J Sci Teacher Educ 31(7):802–820. https://doi.org/10.1080/1046560X.2020.1800195

Niemi H (2002) Active learning—a cultural change needed in teacher education and schools. Teach Teach Educ 18(7):763–780. https://doi.org/10.1016/S0742-051X(02)00042-2

O'Meara N, Fitzmaurice O, Johnson P (2017) Old Habits Die Hard: An Uphill Struggle against rules without reason in mathematics teacher education. Eur J Sci Math Educ 5(1):91–109. Available from: https://files.eric.ed.gov/fulltext/EJ1129985.pdf

Penuel WR, Gallagher DJ (2017) Creating research practice partnerships in education. ERIC

Smith K, Sela O (2005) Action research as a bridge between pre-service teacher education and in-service professional development for students and teacher educators. Eur J Teach Educ 28(3):293–310. https://doi.org/10.1080/02619760500269418

Thomas J, Harden A (2008) Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Med Res Methodol 8(1):45. https://doi.org/10.1186/1471-2288-8-45

Vangrieken K, Meredith C, Packer T, Kyndt E (2017) Teacher communities as a context for professional development: a systematic review. Teach Teach Educ 61:47–59. https://doi.org/10.1016/j.tate.2016.10.001

Weller S (2017) Using internet video calls in qualitative (longitudinal) interviews: some implications for rapport. Int J Soc Res Methodol 20(6):613–625. https://doi.org/10.1080/13645579.2016.1269505

'Silent Videoclips' for Teacher Enhancement and Physics in Class — Material and Training Wheels

Matthias Schweinberger and Raimund Girwidz

Abstract Presenting and demonstrating classroom experiments often causes problems for many physics teachers in the first training phase at university as well as for the second training phase at school. A new strategy is to use videos without an audio track ('silent videos'). Student teachers learn to moderate demonstration experiments in a physically and pedagogically suitable way. They generate an audio track that fits to the video clips provided on the internet. The videos show optimised, school-specific set-ups and presentations of key experiments. At the end of the training phase, student teachers should have a repertoire of key experiments. They know how to build an attention-activating and functional set-up of an experiment, which they can present and adequately explain to students at school. The whole training concept is implemented in the teacher training seminars.

1 Introduction

Numerous requirements have to be considered to optimise the demonstration of experiments, e.g. fitting to the given teaching unit and adapting to pupils' prior knowledge. Physics teachers need to have a range of skills to carry out school experiments and incorporate them into lessons. (Trna 2012) One must also think of the function of the experiment in the actual teaching unit, the wording of a precise hypothesis to be examined, and finally, the designing of the experiment together with all pupils (Nawrath et al. 2011). Besides these challenges presenting demonstration experiments often cause problems for the student teachers. In addition to a suitable experimental set-up, which is essential for the successful operation (Schmidkunz 1992; Nehring and Busch 2018), operating various devices simultaneously might also be difficult for the student teachers (Duit et al. 2010). In particular, handling

M. Schweinberger (✉) · R. Girwidz
Ludwig Maximilians Universität, Theresienstr. 37, 80333 München, Germany
e-mail: M.Schweinberger1@physik.uni-muenchen.de

R. Girwidz
e-mail: Girwidz@lmu.de

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_11

the entire experimental set-up during the presentation, controlling all activities in the classroom and steering the pupils' attention to the central aspects of the experiment are important tasks that must all be done simultaneously. Drawing the pupils' attention to the point of action is even more important as the pupils are often far away from the demonstration desk.

To achieve all the goals of the experiment and—at the same time—to enable the pupils to make all the necessary observations, the student teachers must know about all the steps carried out in the experiment. Not only is the sequencing of the individual actions essential, but also the required observation orders and the timing of their application. The student teachers should learn to give pupils sufficient time to carry out the observation. In addition to all these considerations, adequate linguistic support plays a central role in pupils' understanding. A suitable verbal moderation explains the actions just carried out and is intended to draw the pupils' attention to the aspects relevant at the moment.

This is where the training concept comes in. With the help of 'silent videoclips' student teachers can learn step by step how to present a demonstration experiment. By working with these videos, they learn how to create a suitable experimental set-up, how to operate the devices or the sequences of the operating structure. Moreover, they can concentrate utterly on verbal moderation. So far, about 220 key experiments from school physics are available as silent videos on the corresponding web platform (https://www.didaktik.physik.uni-muenchen.de/lehrerbildung/lehrerbildung_lmu/video/index.html, https://www.en.didaktik.physik.uni-muenchen.de/silentvideos/silentvideos.pdf).

2 Methods

2.1 Procedure

'Silent videoclips', which are approximately 2-min recordings of experiments without an audio track, are a central training wheel of the concept. Unlike science explanation videos (Kulgemeyer 2018), these videos do not aim to explain physical content. The videos—as worked out examples (Kirschner et al. 2006) first show the entire experimental set-up with all the necessary tools, which should be available in every school physics lab. To draw the pupil's attention the set-ups are based on the knowledge of cognitive science (Graham 2008). Then the experiment, which is recorded from the pupils' perspective, is presented in real-time. All activities are shown, as they are usually done in a live classroom performance. The whole presentation proceeds at the speed of a real demonstration. No audio commentary is recorded, only the sounds typical of the experiment, e.g. bangs, etc. can be heard.

Like the demonstration of a silent film, the student teachers have to moderate the video and add an audio track. To do this, they create a sound recording for the presented video with the help of a notebook or smartphone (Fig. 1). They can use

Fig. 1 Voiceover of a ‘silent video’ with a standard Andriod smartphone using the app PowerDirector

every free audio recording or video software (e.g. H5P, Itunes, Quicktime Player, PowerDirector®, final cut). The student teachers write a script of the audio track to have all the necessary keywords at hand. Afterwards the recorded audio track is sent to the lecturer and the completed videos are analysed and discussed in a seminar session. In addition to all considerations about the design and implementation of experiments in class, an adequate linguistic support plays a central role in the pupils’ understanding of physics.

Another essential component of the training concept is the corresponding web platform (https://www.didaktik.physik.uni-muenchen.de/lehrerbildung/lehrerbildung_lmu/video/index.html). It provides school and classroom-related supplements such as curriculum references and safety analysis. Guidelines and advice for the implementation of the experiments in class and didactical hints are given. Specific visualisations and simulations are provided additionally.

The web platform with ‘silent videos’, cross-references and the links to school physics including a set of links is accessible to students, to teacher trainees as well as to established in-service teachers. In addition to the German-language web platform (https://www.didaktik.physik.uni-muenchen.de/lehrerbildung/lehrerbildung_lmu/video/index.html), you can find an English list of all video clips on the English part of the platform of the chair of physics education (https://www.en.didaktik.physik.uni-muenchen.de/silentvideos/silentvideos.pdf) (Fig. 2).

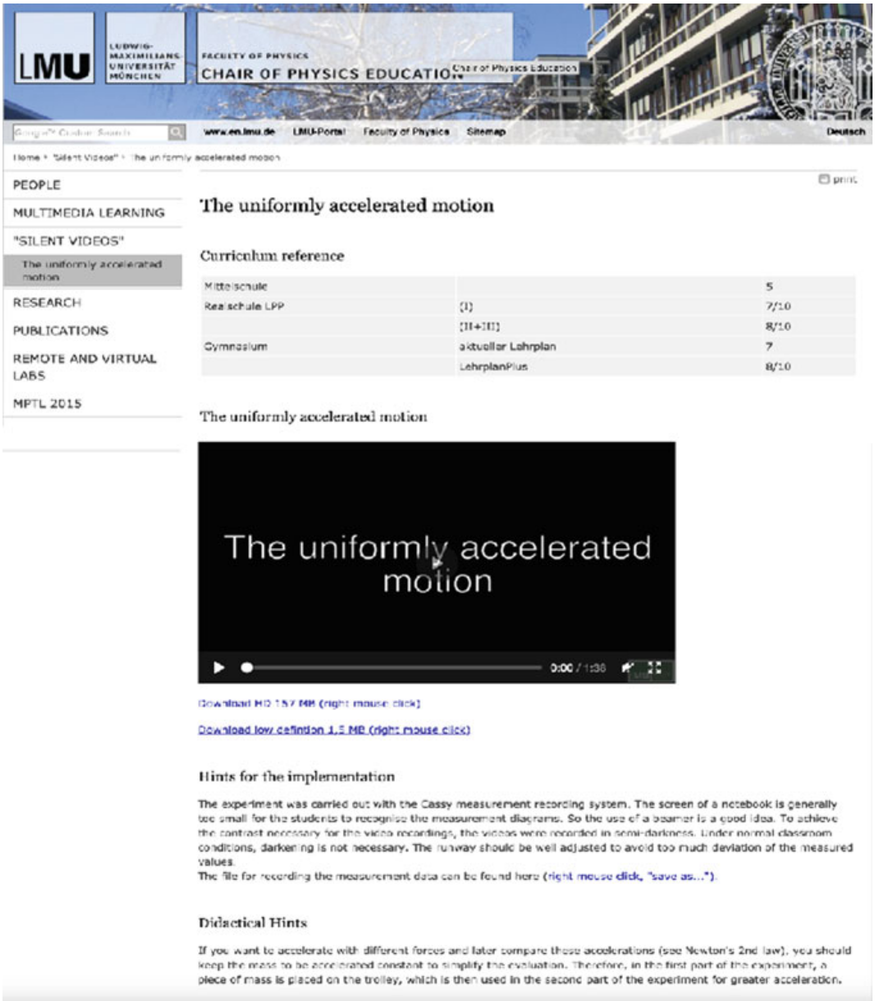


Fig. 2 A sample from the web platform, here 'The uniformly accelerated motion'

2.2 *Criteria for Moderating 'Silent Videos'*

The intended verbal moderation of a demonstration experiment draws the pupils' attention to the aspects relevant at the moment. The pupils should be enabled to perform all relevant observations while the experiment is being demonstrated in class. To achieve this goal, the following list of criteria helps to analyse and evaluate the student teachers' moderations. In each seminar session, the focus is laid on a partial list, to avoid a cognitive overload for the teacher trainees (Fig. 3).

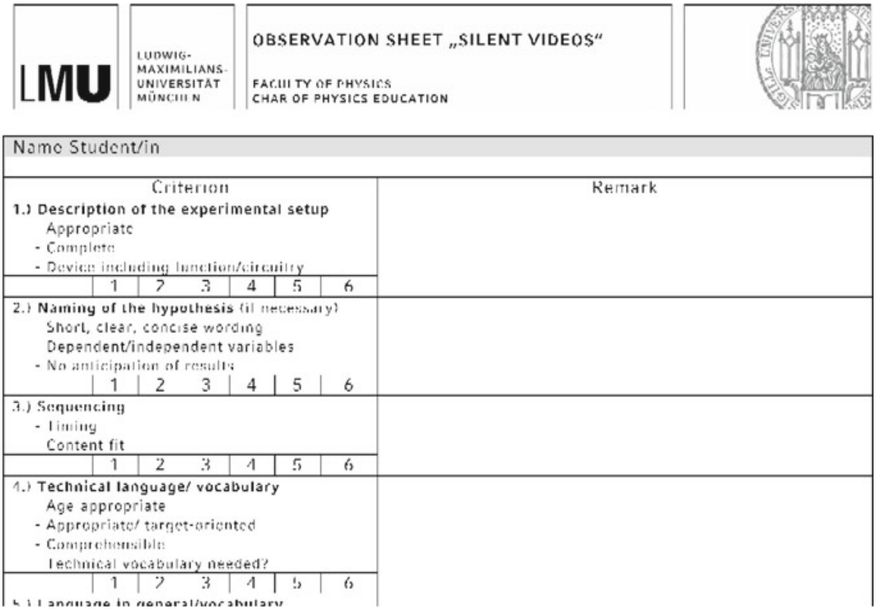
- The student teachers phrase precisely a verifiable hypothesis, using vocabulary appropriate for the pupils.
- They place the experiment shown in the teaching context and relate it to students' existing prior knowledge and a continuation of previous lessons.
- The student teachers clearly distinguish between dependent and independent variables.
- They take up the content and time sequencing linguistically so that their moderation is synchronised with the course of the experimental actions. By labelling the actions at the right time with appropriate technical terms, they control the students' attention and structure the course of action into sub-steps.
- The student teachers use linguistic positioning, which means that they direct the pupils' attention by referring to distinctive visual attributes, for example, surface features such as colour, shape or spatial appearance.
- They try to intensify the pupils' cognitive activity through concrete observation or work assignments.
- Student teachers insert pauses purposefully to give pupils the opportunity to get all the important details.
- They vary their voices (e.g. speed, voicing or volume) according to the situation and adapt their speaking speed to the current requirements of the experiment.
- The student teachers pronounce intelligibly and comprehensibly.
- They use correct grammar and use appropriate vocabulary.
- The moderation is physically correct, but the vocabulary is also adapted to the age and the ability level of the pupils.
- The student teachers collect the observations and summarise them correctly, objectively and factually.
- When phrasing the results, they relate to the hypotheses previously made.
- Observation and explanation must not be mixed in order not to confuse the pupils. Above all, the focus in these training sessions is laid on observation.

Giving student teachers more than three aspects of the presentation as tasks to focus on proved to be impractical and caused a cognitive overload in most cases.

2.3 Development and Implementation of a Training Concept

The following questions defined guidelines for the teaching concept that was implemented in the student teachers' seminars:

- Which new media are suitable for teacher training?
- How can they be implemented in teacher training?
- Do all student teachers have access to these media?
- Are the new methods suitable for distance learning?
- What goals can be reached and are they achieved?
- Is it feasible for students and lecturers to work with it?
- Can students' activities outside the seminar sessions be increased and improved?



LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

OBSERVATION SHEET „SILENT VIDEOS“

FACULTY OF PHYSICS
CHAIR OF PHYSICS EDUCATION

Name Student/in	
Criterion	**Remark**
1.) Description of the experimental setup Appropriate - Complete - Device including function/circuitry 1 | 2 | 3 | 4 | 5 | 6	
2.) Naming of the hypothesis (if necessary) Short, clear, concise wording Dependent/independent variables - No anticipation of results 1 | 2 | 3 | 4 | 5 | 6	
3.) Sequencing - Timing Content fit 1 | 2 | 3 | 4 | 5 | 6	
4.) Technical language/ vocabulary Age appropriate - Appropriate/ target-oriented - Comprehensible Technical vocabulary needed? 1 | 2 | 3 | 4 | 5 | 6	
5.) Language in general/vocabulary	

Fig. 3 Observation sheet

The concept of ‘silent videos’ as a training wheel was implemented in most of the didactical lectures and training seminars at the chair of physics education of the Ludwig Maximilians University Munich. As face-to-face teaching at universities was severely restricted due to the covid-19 pandemic, the idea of ‘silent videos’ was used extensively. Thus, this concept proved to be really suitable for distance learning. The development of the concept resulted in the procedure described below.

The seminars comprised two groups of 10 student teachers. Each of them attended seven sessions for preparation and six sessions were for analysing the recorded moderation. In a first step the training concept was introduced and the student teachers gained first experiences. The tasks were based on H5P, which is a free and open-source content collaboration framework based on JavaScript (https://h5p.org/). Each task includes out of a video player and a voice recorder. The student teachers started the video presentation and recorded their verbal moderation simultaneously. Afterwards they uploaded the audio track to the learning management system ‘Moodle’. In the following session, the audio tracks were linked to the videos.

In addition, the student teachers had to fill in a worksheet on the experiment they work on. This worksheet contains the objectives of the experiment, a list of the devices required and a sketch of the set-up. The student teachers had to describe the implementation including the sequencing of all actions in the experiment as well as the observations to be done by the pupils. This was followed by the physical explanation and the explanation provided for the pupils due to their learning and methodical requirements. The student teachers had to name all competences to be achieved by this experiment.

Before recording the audio track the student teachers had to write a full script of their verbal moderation including all observation orders and the pupils’ answers expected. This is a very efficient exercise to prepare the first attempts at teaching. Both worksheet and script had to be uploaded together with the audio track.

In the preparatory sessions, student teachers are expected to ask for further details on the execution and the implementation of the experiment into the teaching unit. The lecturer or student teachers report different possibilities and ways to teach the topic in class so that the student teachers can weigh the pros and cons of the different approaches. Once they have decided on a teaching way, they prepare the script and make the moderation of their silent video accordingly (Fig. 4).

All the uploaded files are reviewed and returned to the students with individual annotations by the lecturer according to the previously named criteria. In the presentation sessions, the moderations are presented and discussed. The student teachers are encouraged to prepare a new voiceover after the discussion.

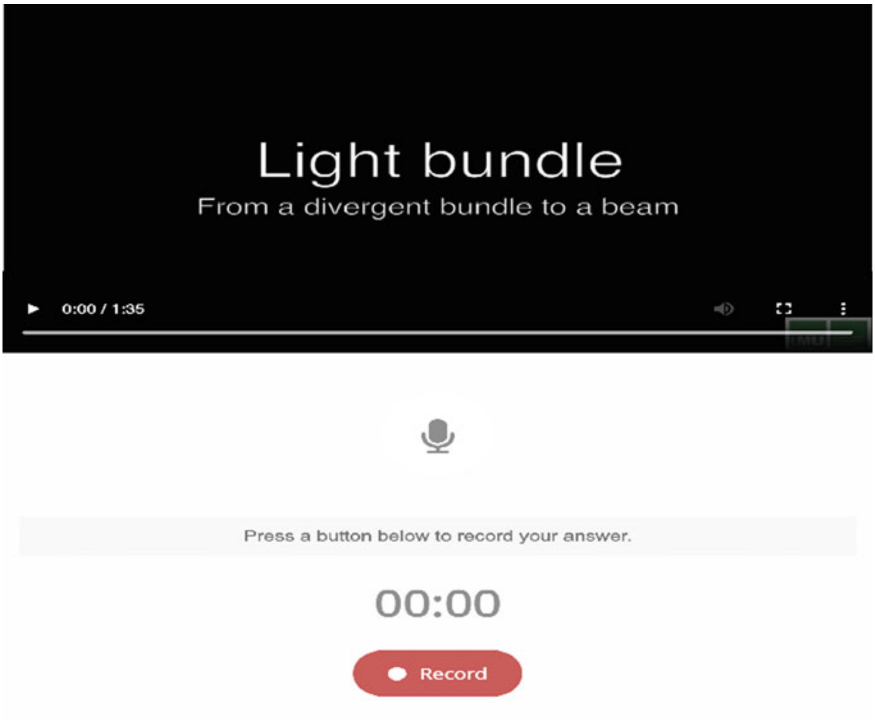


Fig. 4 H5p task with video player and audio recorder

3 Results and Experiences

3.1 Realisation and Experiences

The essential outcome is an adapted concept to implement the special training described above. As already mentioned, it proved to be quite suitable for distance learning and led to self-directed training activities of teacher students. Preparing a moderation of a silent video clip drives student teachers to deal with an experiment intensively. They need to verbalise the requested activities and direct the pupils' attention. The central key questions should be formulated in advance according to the sequences of the experiment.

Student teachers also see the required sequences of the experiment and thus all the actions to be carried out including the necessary repetitions of single sequences. This way they get a feeling for a proper pace of the presentation. In addition, the content knowledge increases, too.

The collaborative analysis of the edited video clips in student groups and during the seminar sessions is extremely intensive and effective. Above all, the possibility of recording the audio track of the experiment again after a discussion is an excellent learning opportunity and teacher trainees can experience their individual learning progress. An analysis of a moderation is shown in the following paragraphs.

The example refers to the formation of shadows when an opaque object is irradiated with two light sources. Figure 5 Pupils in the age of 12 should understand the formation of penumbra and umbra. First lamp 1 is switched on, then lamp 1 is switched off and lamp 2 is switched on, at the end both lamps shine on a piece of wood.

The teacher students recorded their first audio track for this experiment at the beginning of the semester. The second audio was done 3 months later after the

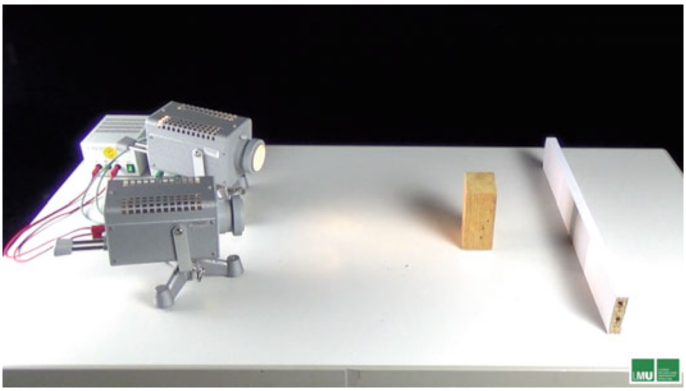


Fig. 5 Overall view of the set-up for core and penumbra formation

		Proportion before/%	Proportion after training
(blue)	information	22	9,4
(light blue)	description of the action	12,5	17,3
(green)	observation order/ question	9,5	14,8
(yellow)	observation time	19,5	39,5
(red)	explanation	5	1,6
(orange)	description observations/ summary	31,5	17,4
	total time	0:40	0:40

Fig. 6 Analysis of an experiment before and after the training with silent videos

training with 'silent videos'. Figure 6 shows the audio tracks before and after the training.

3.2 *Observable Improvements in Moderation*

Relevant changes in the abilities of the student teachers can be seen: Most student teachers decrease either the total length of their moderation or/and the proportion of language. The amount of passive information also drops, while at the same time the proportion of pupil-activating sections increases significantly (Fig. 6: green and yellow), even multiplying for individual student teachers. Especially the wordless sections, where time is given to observe, become more frequent and usually longer. This way the pupils can concentrate on observing and describing student teachers become much more sensitive to the cognitive load of the pupils observing an experiment. In particular, the timing of the descriptions and the working assignments improves, so that the actions and results in the experiment are much easier to recognise. The most important change, however, remains the increase in pupil-activating content and lowering the pupils' cognitive load.

So far, only such quantitative characteristics have been analysed. Data about qualitative changes in the work assignments, key questions used and directing attention indicate promising results, but still require a larger number of subjects.

3.3 Acceptance by Student Teachers

The overall views of the experimental set-ups shown at the beginning of the videos are rated as very helpful by the student teachers, especially when compared to the usual circuit diagrams, illustrations and sketches. Above all, the fact that one can see many experimental details, such as the devices used and their circuitry, is very much appreciated. Textbooks and other manuals usually describe only the set-up of experiments, the execution, including the sequence of content and timing, is rarely discussed practically. The operation of the devices and the realistic implementation in real-time are particularly positively highlighted by student teachers.

Almost all of the settings prepared by the student teachers are discussed in each seminar session. This way the student teachers soon lose their shyness about presenting their works and even expect an individual analysis. Of course, linguistic aspects of an experimental presentation could also be analysed and discussed by using videography. But unlike a videography, the dubbing of a 'silent video' can easily be prepared and made at home. Furthermore, privacy is significantly better preserved by audio tracks compared to video recordings of teaching exercises.

4 Conclusions

Physical experiments are an essential part of school lessons. Future physics teachers, however, often experienced difficulties in putting them into practice. They have to select an experiment that fits the learning objectives, set it up in an attention-grabbing manner and carry it out in a target-oriented way. The pupils must be activated to recognise and summarise the facts to be observed. Student teachers are overwhelmed at the beginning.

New media open new avenues for physics teacher education. Hence, the concept of 'silent videos' is a very successful approach that has proven itself in distance learning. The student teachers specifically train the verbal accompaniment of an experiment with a new computer-based training wheel.

They must deal with the experiment much more intensively, both in terms of the content of physics and didactically. In addition, they learn much about the effective design and the running of an experiment in class. To concentrate on the verbal moderation of experiments in special exercises helps student teachers to improve their linguistic skills in presenting an experiment.

Of course, student teachers must fulfil all the requirements for an experimental demonstration later in class. Practising with ‘silent videos’ cannot replace real experimentation, but nevertheless training with ‘silent videos’ allows to focus on important aspects of an experimental demonstration and to practice under facilitated conditions. But even a perfectly designed experiment fails with poor sequencing, wrong timing, or weak linguistic guidance.

In summary, the concept of the ‘silent videoclips’ offers student teachers an excellent opportunity to improve physical, procedural and verbal skills for experimenting in class.

Acknowledgements The project ‘Silent Videos’ of the Chair for Didactics of Physics at LMU Munich is part of the project Lehrerbildung@LMU run by the Munich Centre for Teacher Education, which is funded by the Federal Ministry of Education and Research under the funding code 01JA1810.

References

Duit R, Tesch M (2010) On the role of the experiment in science teaching and learning—visions and the reality of instructional practice. In: Kalogiannakis M, Stavrou D, Michaelides PG (eds) HSci2010: 7th International conference hands-on science—bridging the science and society gap. The University of Crete, Rethymno, Greece, pp 17–30

Graham L (2008). Gestalt theory in interactive media design. J Humanit Soc Sci 2(1)

Kirschner PA, Sweller J, Clark RE (2006) Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educ Psychol 42(2):75–86

Kulgemeyer C (2018) A framework of effective science explanation videos informed by criteria for instructional explanations. Res Sci Educ 1–22

Nawrath D, Maiseyenka V, Schecker H (2011) Experimentelle Kompetenz - Ein Modell für die Unterrichtspraxis [Experimental competence—a model for teaching practice]. Praxis der Naturwissenschaften - Physik in der Schule, pp 42–48

Nehring A, Busch S (2018) Chemistry demonstrations and visual attention: does the setup matter? Evidence from a double-blinded eye-tracking study. J Chem Educ 95(10):1724–1735

Schmidkunz H (1992) Zur Wirkung gestaltpsychologischer Faktoren beim Aufbau und bei der Durchführung chemischer Demonstrationsexperimente [On the effect of gestalt psychological factors in the construction and performance of chemical demonstrations]. In: Wiebel KH (Hrsg.). Zur Didaktik der Physik und Chemie: Probleme und Perspektiven. Vorträge auf der Tagung für Didaktik der Physik/Chemie in Hamburg, 1991. Leuchtturm, Alsbach, pp 287–295

Trna J (2012) How to motivate science teachers to use science experiments. J Syst, Cybern Inf 10(5):33–35

Toward Teacher Training for Teaching Quantum Physics in High School

Avraham Merzel, Efraim Y. Weissman, Nadav Katz, and Igal Galili

Abstract Teachers' training toward teaching quantum physics at the high-school level requires special effort. Many teachers lack the relevant knowledge and pedagogically tend to "chalk and talk". We developed a workshop for high-school teachers to teach this subject differently. We have adopted the approach of "teachers as learners" (Levy et al. 2019) and the method of "active learning". We used the Discipline-Culture (DC) framework (Tseitlin and Galili, 2005) to adequately represent quantum physics as a physical theory—Quantum Theory (QT), including mathematical components (Pospiech et al. 2021) for scaffolding teachers-students' conceptual and quantitative understanding. We present insights from the workshop and teachers' training for teaching quantum physics in secondary schools.

1 Educational Context

Given the growing interest in teaching quantum physics in high-school as well as the challenging nature of this realm of knowledge, there is a need to upgrade the pertinent teachers' background. The important questions regarding such teaching address (1) the content of quantum physics as Quantum Theory (QT), (2) the arrangement of the chosen content of QT, (3) its mathematical level, and (4) the effective pedagogical means. Also, an effective goal is to encourage teaching the subject given its complexity and presently underrepresented curricular status.

Our answers to the first two questions are provided more elaboratively elsewhere (Pospiech et al. 2021; Weissman et al. 2019), but we briefly present them here to delineate the educational context. The first question has two possible answers: a traditional disciplinary way or the recently developed framework of Discipline-Culture (DC approach) (Tseitlin and Galili 2005; Galili 2019). Within the first option, the curriculum includes the principles of the QT (*nucleus*) and the application of these principles to representative examples and phenomena explanation while introducing the new formal tools (*body*). Within the second option that we chose, the curriculum

A. Merzel (✉) · E. Y. Weissman · N. Katz · I. Galili
The Hebrew University of Jerusalem, Mount Scopus, 9190501 Jerusalem, Israel
e-mail: avraham.merzel@mail.huji.ac.il

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_12

additionally includes references to the alternative accounts of the same subject (*periphery*). While the traditional teaching, such as of classical mechanics, often follows the historical path of an unfolding construction in a kind of reconstruction with students imitating physicists in their inquiry, exploration, and discovery, introducing QT has to take a different approach given an extremely reduced time slot of the curriculum and, at the same time, the much less plausible nature of the QT content. The DC approach is not arranged in a historical order and its curriculum is structured in a triadic manner: principle of QT (nucleus)—illustrative experiment/phenomenon (body)—the reference to the alternative accounts within classical theory (periphery).

The specific mathematical elements of QT formalism (the third question) are introduced in presenting the nucleus—the quantum principles of superposition (*wavity* of matter), the concepts of state and its features (spin, polarization), probability and uncertainty, the possibility of non-coexisting physical quantities (uncertainty principle). The body knowledge includes such elements as two-slit interference, Stern-Gerlach experiment, quantum cryptography, and more (Pospiech et al. 2021; Weissman et al. 2019). Our teaching/learning sequence follows the path of elevating the degree of abstractness in representations (Pospiech et al. 2021), from the concrete to the mathematical formalism while using Dirac notations to allow the quantitative account of quantum phenomena at the most simple but still representative manner.

It is, however, the fourth question that addresses the pedagogical means of our teaching QT that we address here since even though teachers might be proficient in the content knowledge of QT, without proper pedagogical-content knowledge they will not be prepared to teach QT in school (Pospiech and Schöne 2014). For its highly non-obvious content teaching, QT is very often teacher-centered. It is also very demanding as the teachers usually learned the subject often only in introductory university courses and often have no experience in its application. Also, the direct instruction of teachers "what to do" was found to be of low effectiveness (Cordingly et al. 2015). Seeking application of the alternative constructivist approach and learner-centered teaching suggests new ways such as active learning (Desimone et al. 2002), developing special materials (Michelini et al. 2004), interactive activities developing self-experience (Darling-Hammond et al. 2017).

These ideas were adopted in our approach to planning and performing a workshop introducing the new framework of presenting QT in high school. In the workshop, physics teachers had to familiarize themselves with the new approach to teaching content and experience the proposed activities as their students will in the future (Levy et al. 2019). They were encouraged to develop their own teaching activities, based on those which were presented to them in the course of the workshop.

2 Research Questions

The following questions were posed in our study:

1. What are the range of teachers' views and their evaluation of the new approach and developed materials?
2. What can we learn from it about teachers training for teaching quantum physics?

3 Methodology

3.1 Workshop Structure

We planned and executed a workshop for in-service physics teachers. Out of three days of gathering (9 h each), during the first two consecutive days, teachers explored the activities designed, addressing QT as a theory arranged in DC framework (Tseitlin and Galili 2005; Galili 2019). It included components of different levels of abstraction supporting conceptual and quantitative understanding (Pospiech et al. 2021). It was based on activities that we developed and studied (Pospiech et al. 2021; Weissman et al. 2019). The following discussions on the physics content and pedagogy in each activity stressed the students' difficulties, documented (e.g., Krijtenburg-Lewerissa et al. 2017) and of our own experience (Pospiech et al. 2021). In addition, it included raising ideas for other options to teach this content. The third day of the workshop was a few weeks later. The teachers were asked to plan new activities by the third meeting. They worked alone, in pairs or in groups of three teachers. They could get advice from researchers on content knowledge and pedagogical issues. On the third day, the teachers visited university labs and conversed with researchers in QT on current research. Later, they presented their new activities to their peers in the first experience of teaching and learning. The last part of the workshop of 2020 was in the on-line format. The activities were uploaded to a joint website that accompanied the workshop and is open for the teachers' use, including the pre-planned activities.

3.2 Population

Two groups of teachers participated in our workshops. In spring 2019, the first group composed of 15 teachers. Over 25 teachers subscribed to the second workshop of summer 2020. However, due to pandemic constraints, only 13 teachers could participate. The teachers had very diverse academic backgrounds, from physics to engineers and even chemistry. The teaching experience of the participants varied in the range from 1 to 20 years of teaching high-school physics.

3.3 Data Collection and Analysis

The workshop was video-recorded. The teachers filled pre- and post-questionnaires of open and closed questions of understanding the subject matter, nature of science, and teachers' thoughts about teaching QT in their high-school classes. We have applied content analysis (Vaismoradi 2013) done independently by the two first authors and compared and discussed it until reaching a full agreement. We then applied some quantitative analysis according to the results. We elaborate on the analysis in the next section.

4 Results and First Insights

We report here on aspects regarding teachers' responses to the questionnaires. We present teachers' views about the content knowledge, about the training method, and about the effect of using the DC framework for constructing QT to students in the secondary school level.

4.1 Content Knowledge

Insufficient QT knowledge We asked the teachers several open-ended questions regarding the subject matter and to explain their answers: (1) "What is the minimum number of electrons in the double-slits experiment required for an interference to *occur*?", (2) "What is the minimum number of electrons in the double-slits experiment required for detecting an interference *pattern* on the screen?", (3) "If we shoot *one electron* in the double-slits experiment, what will be seen on the screen?" and (4) "What is wave-particle duality?". Since these were open-ended questions, a content analysis (Vaismoradi 2013) was made for each question separately followed by categorization. In these questions, a full agreement regarding the categorization was easily reached between the authors.

The responses to questions 1 and 2 were sorted roughly to correct or incorrect, whether they stated that one electron is sufficient (Figs. 1 and 2). It is worth mentioning the incorrect answers which stated that one electron is enough for detecting the interference *pattern* (21.43% prior and 13.04% after the workshop). We may call this conception "hyper-quantization" and consider it an over-generalization of the interference concept. A similar development is known to be a phase in learning language (Taylor 1974) and mathematics (Dooren et al. 2005). It indicates the dynamics of learning taking place.

The categorized responses to question 3 show three types of responses: the correct one of a single point on the screen, the hyper-quantization of stating an interference pattern (28.57% pre and 13.04% post), and other incorrect responses (most of them

Fig. 1 Responses to question 1—minimum electrons for interference occurrence

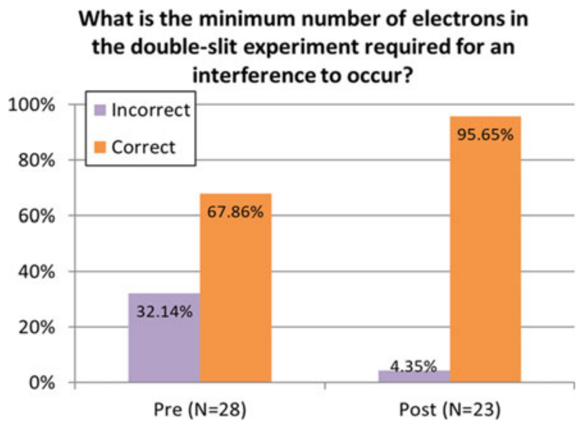
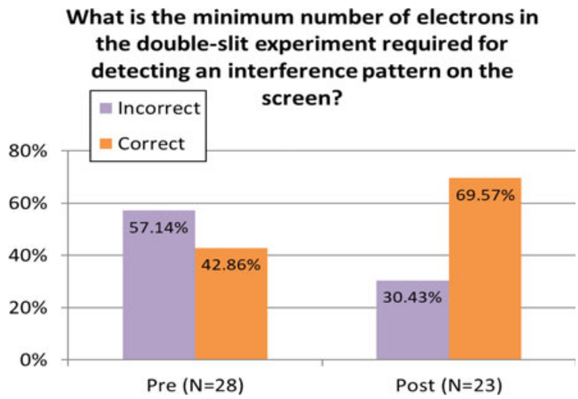


Fig. 2 Responses to question 2—minimum electrons for interference pattern on the screen



were "I don't know"). The results are presented in Fig. 3 (The incorrect responses collapsed together).

The responses to question 4 (Fig. 4) provided three categories that represent for us the level of understanding. The responses that seem like rehearsing the question—"Every particle is a wave and every wave is a particle"—were identified with the responses like "I don't know", both indicating the lower level. Correct answers without elaboration are ascribed to a higher level of understanding. This category included a mere mentioning of the de-Broglie relation, the claim that a particle can interfere, and that a particle sometimes behaves as a wave and sometimes as a particle. The highest level of understanding was ascribed to the answers that stated that a particle has wave qualities and explained the meaning of "wavity" as a possibility that the particle is in a superposition of states which "interfere". Another variant of explanation stated that a particle is "accompanied" by a wave entity that is spread all over the space.

In our view, these results clearly indicate the need to strengthen teachers' proficiency in the fundamental conceptions of the QT. The lack of such knowledge directly

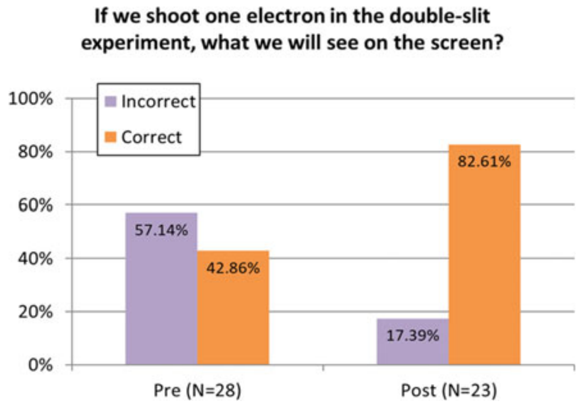


Fig. 3 Responses to question 3—What will be seen on screen if one electron is shot

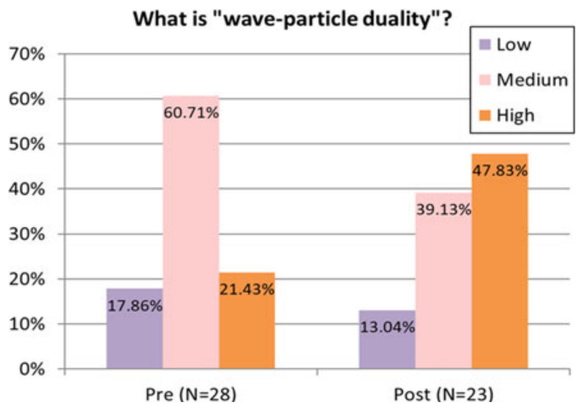


Fig. 4 Responses to question 4—What is "wave-particle duality"

influences teachers' self-efficacy as we observed in their responses to our inquiry after the workshop. There we asked if they consider teaching quantum physics in their classes. Using the same qualitative method applied above, we identified three levels of low, medium, and high self-efficacy of teachers' knowledge. The low level included the responses admitting the feeling of incompetence in teaching quantum physics. For example, one of the teachers said:

> This is not an intuitive theory, and hence it is difficult to understand (for me too…) and to teach students. I would like to know more about the subject matter and then I could teach it. (teacher 10)

Another teacher said:

> Right now, I don't feel ready to teach QT in my class. I will not teach students a subject which I don't understand well enough myself…. (teacher 21)

The medium level of self-efficacy included responses that consider teaching quantum physics while still expressing some hesitations. For example, teachers said:

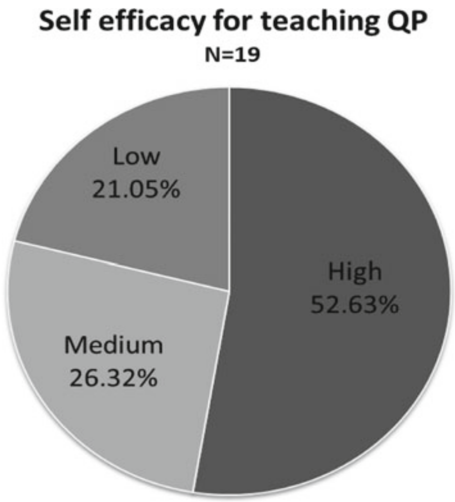


Fig. 5 Self efficacy for teaching QP

> It is possible to teach QT following the program ((provided)). I think that I need ((to invest)) time and effort before I will feel comfortable to teach it. (teacher 16)

> I need to undergo a process before I decide to teach this subject. (teacher 19)

Finally, the teachers with high level of self-efficacy manifested wholeheartedly that they will teach quantum physics in their classes. For example, they said:

> I will definitely teach quantum physics, at least the parts we were discussing in the workshop. (teacher 9)

> Next year I definitely plan to teach it. I hope the school will allow it. (teacher 5)

In these responses, we see the connection between self-efficacy and proficiency in the subject matter. The distribution of the responses (Fig. 5) shows that almost half of the participants (47.37%) do not feel confident enough in the subject matter to teach it. One may speculate that teachers who choose to participate in our workshop were those with the less knowledge, and their colleagues do master QT. This speculation is less plausible, however, since quantum physics is currently outside of the requirement in our schools and teaching it requires a special approval from the ministry of education (which our program has). It is thus more plausible that teachers who participate in our workshop are those who consider teaching quantum physics while other teachers do not.

Need for support Teachers considered the support that they got in the workshop as essential. The consultation and guidance were provided by our team composed of a physics professor (third author) and physics education researchers (all other authors). Of them, two serve as physics teachers in secondary school and college (first and second authors). The support was both in content knowledge of QT and pedagogical considerations regarding the technological platform and teaching/learning sequence organization. The respondents expressed their appreciation in the feedback questionnaire at the end of the workshop. For example, they wrote:

> The task was interesting and challenging… The available support that we got allowed us to proceed. (teacher 24)

> It was good to process things and develop learning materials in groups during the training, with consultation and guidance. (teacher 13)

A different kind of support that relates content knowledge to self-efficacy was mentioned also with regard to whether they would teach quantum physics in their classes. Lacking appropriate textbooks, the teachers expressed an interest in creating canonic knowledge at the high-school level that would help in teaching the subject. We addressed this need by preparing a special "teachers' guide for teaching QT in secondary school level" for the workshop.[1] We continued to improve it between the first and the second workshops. Thus, we answered the request:

> I suggest to prepare two-three exercises of Dirac notations with explicit and very elaborate solutions step by step. (teacher 1)

Others wrote:

> For me, to take a chance and "dare" to teach quantum physics, I should get a safety-net of very organized books. (teacher 21)

> The teacher's guide looks excellent and is very helpful in organizing the knowledge. It will help in preparing lesson plans. (teacher 3)

> I'll be honest, I don't know quantum physics well enough… So, at the moment, I'll stick to the teachers' guide. (teacher 13)

> This training program has a complete package that provides content to be studied in a modular manner, which is a great advantage. (teacher 4)

The training method Teachers viewed themselves as learners of QT, apparently due to insufficient knowledge as they perceived it. Therefore, they referred to their learning as an important part of their own training, as some teachers said:

> In my opinion, teachers' knowledge and understanding should be first established, and only then, in another workshop, to talk about pedagogy. (teacher 2)

> Also…our experience in solving exercises is very important. (teacher 4)

> It would be better to incorporate exercises of Bra-Ket earlier in the workshop. (teacher 5)

> I felt confident with the work-alone learning. When I needed a little guidance, I got it. ((Yet,)) personally, I would like a bit more explanations instead of self-learning. (teacher 11)

Teachers also referred to the task of composing teaching activities and peer teaching with feedback as important and interesting and as part of their learning. They wrote:

[1] https://qcent.huji.ac.il/teaching-materials

> The task was very good for me (despite the tight schedule). It forced me to study the related topics in depth and sharpen my understanding. Also, the other groups' activities were enlightening. (teacher 5)

> Presenting our activities to each other was good... We also learned new things. Performing the tasks helped to internalize ((the ideas)). (teacher 17)

> The presentations of the participants were quite successful and touched on several aspects, so that they helped to formulate an understanding of what is suitable for teaching and what is less. (teacher 21)

> It was interesting to see other teachers' ideas and materials … It was a reasonable task. The teachers' materials were diverse, but I presume it would be better to present them according to the sequence of the teachers' guide. (teacher 22)

4.2 Nature of Science

At the end of the workshop, we asked the teachers what did they learn in the workshop that could be useful to their teaching of classical physics without mentioning the DC framework explicitly. In another questionnaire, later, we asked them whether they thought that the DC framework is applicable to teaching physics in school. Both questions were open-ended. We analyzed the responses thematically only regarding the DC framework. We found that eight out of the 11 responses (about 73%) mentioned DC as a helpful organizing tool for teaching.

> The idea of heart [=nucleus], body and periphery helped in organizing things. It also helps a bit to talk about the philosophy of science. (teacher 2)

> My pedagogical-teaching worldview was extremely changed. ((I learned)) the meaning of a physical theory (nucleus vs. periphery). [...] It might seem small, but I think it will affect my teaching a lot. (teacher 4)

> I always had an undefined division in my head between the heart [=nucleus] and the periphery or applications of what is learned, and in this workshop this insight took a significant form. (teacher 9)

> I will include the DC terminology, for example in Newton's laws in relation to Aristotle. (teacher 10)

Interestingly, the response of teacher 10 indicates a resonance with teachers' knowledge already existing in some of them. Nine of 11 respondents (about 82%) mentioned the DC approach as applicable in class. Of them, six teachers were explicit about using this framework while teaching both classical and quantum physics, two teachers mentioned explicitly only classical physics in this regard, and one teacher mentioned using this framework explicitly only for teaching QT and as unnecessary in teaching classical mechanics. Among the two teachers who did not see this approach as applicable in class teaching, one teacher wrote that he would still use it while preparing lesson plans, as a thinking tool.

5 Discussion and Conclusion

The growing importance of teaching quantum physics at the high-school level requires suitable training for teachers. We planned and executed two rounds of such in teacher-workshops in 2019 and 2020, in which 28 teachers participated. This workshop was organized in accordance with the approach of "teachers as learners". We framed QT using the DC approach of modular structure and supported the participants in their own planning of learning and teaching their peers. Using pre and post-questionnaires we elicited teachers' views and their evaluation of the new approach and developed materials. We drew insights about teachers training for teaching quantum physics.

In accordance with others (Michelini et al. 2004), it seems that teachers' proficiency in the subject matter is not always sufficient or adherent with the scientific consensus. We have found this affects their self-efficacy in subsequent teaching. Hence the training programs for QT teaching at the high-school level are required to fill the gaps. We argue that taking the "teachers as learners" approach seems important for such training. This approach allows teachers to solidify their content knowledge in a psychologically comfortable environment providing both content and pedagogical-content support. The teachers were expected to learn (including making mistakes) without being judged or evaluated. Doing so along with the growing degree of abstractness of representations (Pospiech et al. 2021) created an appropriate way of learning. Experiencing both "hats"—as learners and as teachers—seemingly increases self-efficacy in teaching QT even within our qualitative analysis.

Unlike classical physics, where teachers are more experienced and prepared, they can rely on plenty of resources, there are significantly less resources for teaching quantum physics in secondary school. This fact has two implications: The support and guidance given to the teachers should contain both physics content knowledge and pedagogical-content knowledge regarding QT. Such assistance should be accessible and available. We recommend training programs addressing specific groups of school teachers with participation of experts in QT. They may contribute in planning lessons in quantum physics, designing activities, and providing pertinent support in the especially sophisticated knowledge of quantum physics which presents a subject still without a stable teaching tradition and content interpretation appropriate for school students.

The second implication has to do with curriculum as a resource. Teachers consider curriculum as a resource for lesson design (e.g., Brown 2011; Beyer and Davis 2009). Therefore, there is a need for a special product that would represent a kind of canonical knowledge of the subject appropriate for high schools. It is important to note that we do not aim to a one-size-fits-all curriculum, but a growing research-based reservoir of teaching and learning sequences and activities, developing various platforms and methods of assessment from which school teachers could select, adopt and adapt in designing their own lessons addressing their specific student population.

The task of developing the required activities turned out to be an effective mode of training. Firstly, it increased teachers' content knowledge of QT and their proficiency in teaching this subject. This activity forced teachers to look for information on the web or ask experts included in the training team. Secondly, it increased teachers' ownership and confidence regarding QT. Thirdly, designing activities for teaching and learning is time-consuming and by allocating this activity in the workshop, we provided teachers with an opportunity to create a personal arsenal of such activities. It can motivate them to teach quantum physics in their classes, even if it is currently outside of the mandatory curriculum in our country. This activity can prepare the required curricular change in our educational system.

The framing of QT through DC perspective touches on the issues regarding the nature of science which teachers typically ignore in the disciplinary instruction of classical physics, yet the latter also benefits from the contrast with QT (Pospiech 2000). It makes the conceptual framework for the curriculum explicit (Tseitlin and Galili 2005; Galili 2019). Moreover, since such teaching does not follow a historical path of physics, it suits the short time allocated, if at all, for meaningful teaching of quantum physics in high school. Furthermore, the cultural teaching of this domain of physics projects on students' knowledge of the previously learned domains of classical physics (mechanics, optics, and electromagnetism) provides a universal framing of the physics content for teaching and learning physics in secondary school.

References

Beyer CJ, Davis EA (2009) Using educative curriculum materials to support preservice elementary teachers' curricular planning: a comparison between two different forms of support. Curric. Inq. 39:679–703. https://doi.org/10.1111/j.1467-873X.2009.00464.x

Brown M (2011) The teacher-tool relationship: theorizing the design and use of curriculum materials. In: Remillard JT, Herbel-Eisenmann BA, Lloyd GM (eds) Mathematics teachers at work: connecting curriculum materials and classroom instruction. Routledge

Cordingly P, Higgins S, Greany T, Buckler N, Coles-Jordan D, Crisp B, Saunders L, Coe R (2015) Developing great teaching lessons from the international reviews into effective professional development. Durham University, London

Darling-Hammond L, Hyler ME, Gardner M (2017) Effective teacher professional development, 76

Desimone LM, Porter AC, Garet MS, Yoon KS, Birman BF (2002) Effects of professional development on teachers' instruction: results from a three-year longitudinal study. Educ Eval Policy Anal 24:81–112. https://doi.org/10.3102/01623737024002081

Galili I (2019) Towards a refined depiction of nature of science: applications to physics education. Sci Educ 28:503–37. https://doi.org/10.1007/s11191-019-00042-4

Krijtenburg-Lewerissa K, Pol HJ, Brinkman A and van Joolingen WR (2017) Insights into teaching quantum mechanics in secondary and lower undergraduate education. Phys Rev Phys Educ Res 13:010109. https://doi.org/10.1103/PhysRevPhysEducRes.13.010109

Levy S, Bagno E, Berger H and Eylon B-S (2019) Physics teacher-leaders' learning in national program of regional professional learning communities. In: 2018 Physics education research conference proceedings 2018 physics education research conference. American Association of Physics Teachers, Washington, DC. https://doi.org/10.1119/perc.2018.pr.Levy

Michelini M, Ragazzzon R, Santi L and Stefanel A (2004) Implementing a formative module on quantum physics for pre-service teacher training. In: Michelini M (ed) Quality development in teacher education and training: second international GIREP seminar 2003 ; selected contributions

; [1–6 September 2003, Udine, Italy] Groupe International de Recherche sur l'Enseignement de la Physique Udine: Forum, Ed. Univ. Udinese, pp 429–35
Pospiech G (2000) A modern course in quantum physics for teacher education. In: Xingkai L, Kaihua Z (eds) Turning the challenge into opportunities. Guangxi Normal University Press, Guilin, China, p 4
Pospiech G and Schöne M (2014). Quantum physics in teacher education. In: Sidharth BG, Michelini M, Santi L (eds) Frontiers of fundamental physics and physics education research; Springer proceedings in physics, vol 145. Springer International Publishing, Cham, pp 407–16. https://doi.org/10.1007/978-3-319-00297-2_40
Pospiech G, Merzel A, Weismann E, Katz N, Galili I, Zuccarini G, Santi L, Michelini M (2021) The role of mathematics in teaching quantum physics at high school. In: Jarosievitz B, Sükösd C (eds) Teaching-learning contemporary physics: from research to practice, challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-030-78720-2_4
Taylor BP (1974) Toward a theory of language acquisition1. Lang Learn 24:23–35. https://doi.org/10.1111/j.1467-1770.1974.tb00233.x
Tseitlin M and Galili I (2005) Physics teaching in the search for its self: from physics as a discipline to physics as a discipline-culture. Sci Educ 14:235–261. https://doi.org/10.1007/s11191-004-7943-0
Vaismoradi M, Turunen H, Bondas T (2013) Content analysis and thematic analysis: implications for conducting a qualitative descriptive study. Nurs Health Sci 15:398–405. https://doi.org/10.1111/nhs.12048
Van Dooren W, De Bock D, Hessels A, Janssens D and Verschaffel L (2005) Not everything is proportional: effects of age and problem type on propensities for overgeneralization. Cogn Instr 23:57–86. https://doi.org/10.1207/s1532690xci2301_3
Weissman E Y, Merzel A, Katz N, Galili I (2019) Teaching quantum mechanics in high-school—discipline-culture approach. J Phys Conf Ser 1287:012003. https://doi.org/10.1088/1742-6596/1287/1/012003

Teaching Approaches to Facilitate Learning

Toward Types of Students' Conceptions About Photons: Results of an Interview Study

Philipp Bitzenbauer and Jan-Peter Meyn

Abstract We report an exploratory interview study into students' conceptions of photons developed by learners introduced to a QED model of photons as part of an introductory course in quantum physics at the secondary school level. By combining qualitative and quantitative research methods, we extract types of students' imaginations about photons. Furthermore, we show that teaching a QED model of the photon might help to circumvent known (naive) particle notions of the photon.

1 Wave-Particle-Duality and Photons in Physics Education

Wave-particle-duality is a key item in international curricula on quantum physics in schools (Stadermann et al. 2019). It is usually taught using historical approaches or mechanistic analogies (Greca and Freire 2003), e.g., referring to naïve ontologies in quantum physics lessons (Ayene et al. 2019). Against the backdrop of these mechanistic analogies, the wave-particle-dualism often leads to fundamental misunderstandings about quantum physics among students, cf. (Olsen 2002; Henriksen et al. 2018). Although many experts consider wave-particle duality to be an essential topic for teaching quantum physics at the secondary school level (Krijtenburg-Lewerissa et al. 2018), some researchers suggest a rejection of the (naïve) wave-particle duality in introductory courses on quantum physics because of the aspects mentioned above. For example, Jones stated in Ref. (Jones 1991) that it "produces half-baked and incorrect conceptual models which stunt understanding and the development of interest" and Hobson (2007) believes that the wave-particle dualism may yield confusion among students about how to view quantum objects such as electrons or photons.

Therefore, Hobson recommends introducing electrons and photons as "quanta of various continuous space-filling fields" (Hobson 2005, p. 61). In line with this, Jones affirms about photons that "the physical picture of the radiation field produced by quantum electrodynamics (QED) is satisfactory" (Jones 1991, p. 97). Bronner et al.

P. Bitzenbauer (✉) · J.-P. Meyn
Physics Education Research, Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
e-mail: philipp.bitzenbauer@fau.de

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_13

argue that by referring to quantum electrodynamics in teaching quantum physics, it may be possible to circumvent familiar particle conceptions about the photon and instead open a range of potentials for physics teaching (Bronner et al. 2009). For example, demonstration experiments with individual photons are now accessible for educational purposes (Dehlinger and Mitchell 2002; Galvez et al. 2005; Thorn et al. 2004; Scholz et al. 2018). Also, in this way, the Qubit, as the simplest quantum state in Hilbert space, can easily be treated with the help of the linear polarization of photons, cf. (Michelini et al. 2000; Dür and Heusler 2014).

This contribution presents an approach to integrating a QED model of photons into secondary school teaching (cf. Sect. 2). In a first exploratory interview study, which we report from Sect. 3 onwards, we seek to identify the conceptions learners develop about photons when they are introduced to quantum physics using the Erlangen concept. Finally, we discuss the results of this interview study with results of previous studies on students' conceptions of photons from literature.

2 The Erlangen Teaching Concept on Quantum Physics

We presented our teaching concept in detail in an earlier contribution (Bitzenbauer and Meyn 2020) and therefore only outline the core ideas of the concept here to sketch how a QED model of the photon is taught. Our secondary school concept (11th/12th grade) is structured into two main parts (4 lessons in total, 90 min. each). The focus of our concept is on coincidence and correlation experiments with single photons. Concretely, these are experiments with announced photons. The essential aspects of quantum optical experiments are covered during the first two lessons. In lessons three and four, the experimental results from single-photon experiments can be interpreted. We provide interactive screen experiments of these experiments developed by Bronner et al. (2009) for teachers and students who do not have access to a quantum optics laboratory.

We start with our concept of introducing single-photon detectors, namely avalanche photodiode, APD. The reason is simple: it is a widespread conception that every click of such a detector is due to the detection of a single photon (Henriksen et al. 2018), but this is not the case: Instead, APDs themselves are subject to a stochastic process—the temporal distribution of clicks is Poissonian, even without illumination (Bitzenbauer and Meyn 2020). We emphasize this from the beginning to prevent particle conceptions of photons and to lay the foundation for understanding the preparation of single-photon states. The latter is experimentally done with the coincidence technique: A click at one detector (called Bob) is a necessary condition for a photon at the second detector (called Alice). Simultaneous clicking of the detectors in both arms of the experiment is called a coincident event. Such a coincidence event of the two detectors defines the preparation of a single-photon state. This approach is in accordance with a QED model of the photon: the photon is regarded as an excitation of the electromagnetic field, and the more energy is irradiated on the APD, the more coincident events, i.e., the more photons per second, are measured.

In lessons 3 and 4, the coincidence experiment is extended to investigate photons' properties based on the publication by Grangier et al. (1986). In a first step, the anti-correlation at a beam splitter is discussed, leading to photons' indivisibility. In the second step, single-photon interference using a Michelson interferometer is introduced to the students. These experiments' results mean that the idea of the photon as a localizable particle must be dropped. Showing anti-correlation of photons and single-photon interference in one experiment at a time makes it clear that a photon cannot be a particle in a mechanical sense and reinforces our QED model of photons as an excitation of the electromagnetic field. Thus, students develop an understanding of photons as energy quanta. The Erlangen concept's teaching material can be requested from the corresponding author in either German or English by e-mail. An investigation of teachers' practical experiences with our teaching concept and the related materials revealed that "teachers predominantly assess the materials as positive […] and emphasize, for example, the close reference to current research or the orientation of the concept to experiments" (Bitzenbauer 2021a, p. 13).

3 Research Questions

We conducted an acceptance survey to evaluate the Erlangen teaching concept during its development (Bitzenbauer and Meyn 2020). A mixed-methods design is used to investigate the Erlangen concept's learning effectiveness using various qualitative and quantitative empirical research methods. However, our research questions go beyond a mere learning gain: Providing a detailed picture of quantum physics in general and photons, in particular, is a central goal of the Erlangen teaching concept of quantum physics. Therefore, we are particularly interested in the conceptions of photons developed by students who are introduced to quantum physics with this new curriculum. In this article, we consequently address two research questions:

1. Which conceptions about photons are held by students who are introduced to quantum physics with the Erlanger teaching concept?
2. Which types of learners' conceptions about photons can be found?

4 Design of the Study

For the summative evaluation of the Erlanger teaching concept, a total of 171 learners from 12 German secondary schools were introduced to quantum physics using the Erlanger concept. The participants' prior knowledge was assessed using a pre-test on declarative knowledge of quantum physics (Bitzenbauer 2021b).

4.1 Methods and Participants

A random sample of N = 25 students from the total sample was interviewed after the intervention (15 male, 10 female) to identify students' conceptions about photons that are fostered by introducing students to quantum physics using the Erlanger teaching concept. These interviews were planned as one-to-one semi-structured interviews. We used an interview guideline which is the result of an iterative development process, including a pilot interview and expert discussion as recommended in McGrath et al. (2019) and includes

- the procedure to be followed by the interviewer,
- keywords for a preamble to address confidentiality and consent issues,
- questions to be asked,
- follow-up questions to help participants expand their answers, and
- a concluding acknowledgment.

as suggested in Bolderston (2012). The students were asked different questions during the interviews that provided insights into the learners' associations with photons in different contexts. For example, the interviewees were asked to (a) describe their imaginations of photons, (b) they had to explain experimental set-ups, and had to comment on the meaning of the experiments' results for our understanding of photons (e.g., double-slit or Michelson interferometer experiment) or (c) they had to discuss citations on photons (or light quanta) from famous physicists, e.g., Einstein.

4.2 Data Analysis

The interviews were recorded and transcribed directly after the interview according to defined criteria.

Analysis carried out to answer research question 1

With the help of deductively and inductively formed categories, the students' answers were analyzed through qualitative content analysis (Mayring 2000). Table 1 shows the definitions of the five categories found, including anchor examples. Independent coders performed the coding with a high agreement ($\kappa = 0.85$).

Each category is treated equally in the coding. However, subsequent occurrences of the same category in a participant's transcript are not coded, as the repetition of the same expression or the repetitive use of related statements does not provide new insights into participants' conceptions. Frequency analysis is applied to count a category's occurrence and helps clarify research question 1.

Analysis carried out to answer research question 2

Since we are interested in isolated conceptions (as discussed in research question 1) but also in the underlying structure of students' conceptions about photons, a cluster

Table 1 Categories that were used to analyze the interview data

Category	Definition	Anchor example
Naive particle notion [ParticleNotion] (adapted from Bormann (1986))	Passages that point to an idea of the spherical shape of photons	"*Photons, from my point of view, may be regarded as small balls just like electrons and all other particles*"
Photons as light particles with wave and particle properties [ParticWave] (adapted from Wiesner (1996))	A particle conception is extended by a dualistic description, mixing the model and reality levels	"*Actually, it's more like a particle, but it also has wave properties, so you can't really call it a wave, I think, so for me, it's a particle with wave properties*"
Energy quantum [Energyqu] (adapted from Wiesner (1996))	Photon is seen as energy portion	*"[…] a photon is now, in my opinion, actually a portion of energy that simply cannot be assigned a fixed location at a certain time, so you can say at some times that there was a photon here, but not always.*"
Indifferent Imagination [IndiffImage]	The fact that the particle concept leads to erroneous physical conclusions is well known, but the spherical concept is retained	"*So you must not imagine that photons can be located there, that they have a permanent location, but they simply have no fixed location. You simply can't think of them as particles, as a particle, as a sphere, you simply can't have that idea. It's wrong. And yet I have it. I don't know*"
Particle conception explicitly rejected [RejectParticle]	Text passages indicate that the (naive) particle conception has been explicitly discarded and prove that the subjects are aware that a photon is not comparable to any object in the living world	"[…] *So at school we were always told that photons are particles of light, but* […] *I now know that they are not classical particles because they cannot be permanently localized and photons are indivisible, they have energy and can move*"
Quantum of energy that moves in the form of a wave [QuantWave]	Photon is seen as a portion of energy moving along a wave	"*Well, so I just think of a photon as energy, energy moving in space in waveform*"

In parentheses, we give an abbreviation to each category to make it easier to reference the individual categories in the text analysis was conducted to answer research question 2. In empirical research, cluster analysis is an exploratory method to identify groupings within a sample (Eshghi et al. 2011).

Based on the qualitative data from our interview study, we used our categories as binary variables (0 ≙ "Student did not address the category during the interview", 1 ≙ "Student addressed the category during the interview") to conduct cluster analysis, as a simulation study (Henry et al. 2015) provides evidence that hierarchical cluster analysis and K-means work well with dichotomous data and it was found that hierarchical clustering can produce valid solutions for samples as small as $N = 20$.

Hence, in this study, we used hierarchical agglomerative clustering methods using the Manhattan metric and Ward's fusion algorithm (Strauß and Maltitz 2017) to determine the optimal number of clusters. We used a dendrogram to find the cluster solution, and in the following, we conducted a partitioning K-Means cluster analysis to classify clusters (Denis 2020). Concerning the interpretation of cluster analysis results, we follow the suggestions provided by Henry et al. (2015) that for smaller samples (in our study $N = 25$) the solution with few clusters should be preferred to the solution with many clusters because "in addition to taking parsimony into account, the assignment accuracy is higher with fewer clusters, but can decrease rapidly as the number of clusters increases" (Henry et al. 2015, p. 1014).

In this study, the results of the cluster analysis do neither represent generalizable results nor is the cluster analysis conducted to yield valid types of students' conceptions about photons. Much more likely, interpretable clusters in terms of content yield preliminary groups among students with similar ideas regarding photons. However, they may function as a starting point for further investigations to determine to what extent teaching a QED model of the photon may foster functional students' mental models of photons. Thus, in subsequent studies with larger samples and quantitative approaches, the findings of this first exploratory investigation will have to be validated. We discuss our exploratory study results against the backdrop of findings from physics education research in Sect. 6 of this article.

5 Results

In this section, we report on the findings of our interview study.

5.1 Results of Qualitative Content Analysis

The percentage of respondents making statements that fall into the respective category is shown in Fig. 1. None of the interviewees expressed a naïve particle conception of the photon during the interview, which can be considered a success. Instead, we found that 32% (8 out of 25) of the respondents explicitly state that visualization

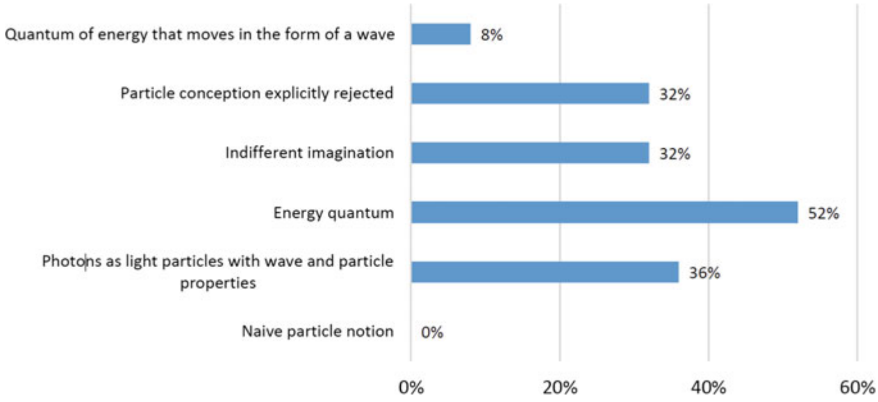


Fig. 1 Percentage of respondents making statements that fall into the respective category

of a photon in the classical sense is not possible and at the same time also emphasize the rejection of a naïve particle image, e.g.:

I: "Okay, so let us conclude what we have discussed so far: what would you say, what is a good imagination of photons?"

B19: "[...] I find this question very difficult to answer because in the past I always imagined photons as particles that float around in the air and that light consists of, but we have learned that they are not real particles that have a fixed location, so at the moment I have no real idea what I can imagine photons to be, because it is simply very difficult to imagine something, somehow, because we don't know anything like that. And we don't have that in our world, so to speak, in what we experience every day, that's why at the moment I don't really have an idea of what it is, because I, what I just, now I know that they are not balls floating around in the air, but I don't really have an idea of it."

Similarly, 32% (8 out of 25) of the respondents express indifferent concerns: although they imagine photons as particles (i.e., as spheres or the like), they claim to know that this image cannot be confused with reality, e.g.:

I: "Would you please reflect models that may help to understand photons and thus conclude how you think about photons?"

B3: "[…] Well, I must say that it was always difficult to say. Maybe I'm referring more to the wave-particle dualism, although I know it's not right, but somehow you have to imagine something, your head thinks in images. A particle like that, which is also a wave. I don't know. So you can't say it like that, I already know that, but I would always imagine it as a particle, I think."

36% (9 out of 25) of the interviewees persist in a dualistic conception, thinking of photons as components of light with wave properties, as can be seen, for example, in the following interview extract:

I: "The other task was your own evaluation in conclusion."

B8: "Light has both wave and particle properties, so you can't just assume that light has particle properties, but light still has wave properties, that's wave-particle dualism, should I talk about photons or what?"

I: "Yes, you say wave-particle dualism, that is an interesting term. Does this mean that I can now imagine that photons are both?"

B8: "Yes, so electrons [photons] are both waves and particles, so to speak, and they have properties depending on how you look at them. So how you look at them, in which experiment. Eh, the photons, did I say electrons? The photons."

Most students—namely 52% (13 out of 25)—understand photons as energy portions of light. Alone, this says nothing about the concrete imagination, but the above results reflect one thing: a naive particle conception of the photon is not expressed by any of the respondents. The mixing of different models is also only observed in two cases: 8% (2 out of 25) of the respondents imagine photons as particles moving along a wave, e.g.:

I: "Okay, let's continue. What do you think about photons after these experiments?"

B23: "Well, a kind of energy portion that moves through space with a wave."

I: "You'll have to describe that a little more precisely now."

B23: "Well, we have a photon, so to speak, I imagine as if it was energy that flies through space, and this energy moves through space in the form of a wave."

5.2 *Results of Cluster Analysis*

Initially, the results of coding all student responses were subjected to a hierarchical agglomerative cluster analysis using the Manhattan metric and Ward's fusion algorithm (cf. Sect. 4.2). Taken together, the dendrogram and the arguments relating to content led to a 3-cluster solution. A partitioning K-Means cluster analysis was subsequently carried out. Comparing the respondents' statements within the clusters with those of the total sample yields striking differences between the clusters. These enable the content description of the extracted idea types: In Table 2, the percentages

Table 2 Summary of the three clusters on the students' conceptions about photons

Cluster	#Students	[Energyqu] (%)	[RejectParticle] (%)	[IndiffImage] (%)	[QuantWave] (%)	[ParticWave] (%)
1	9	78	44	0	11	0
2	7	57	0	100	14	0
3	9	22	44	11	0	100

Numbers shown are those of learners per cluster (#Students) and the percentage (rounded) of respondents within the cluster who made statements in their responses that can be assigned to the respective categories. The abbreviations of the categories are those from Table 1 of respondents in each cluster who made statements that can be attributed to the respective categories are shown to indicate this point.

From the results of our cluster analysis, we consequently may give an interpretation of primary students' mental models of photons that arise by introducing a QED model of the photon within an introductory quantum physics course using the Erlanger teaching concept:

Cluster 1: *Elaborated energy quantum notion.* Students in this cluster refer to photons as energy portions or energy quanta in 78% of the cases (7 out of 9, category [Energyqu]). Thereby, no statements appear for indifferent conceptions or indicate that learners think about photons as light particles with wave properties (category [ParticWave]). In contrast, 44% of the respondents in this cluster even explicitly reject a particle conception (4 out of 9, category [RejectParticle]). This cluster includes nine of the respondents, which corresponds to 36% of the total sample.

Cluster 2: *Energy quantum in particle form.* Students in this cluster refer to photons as energy portions or energy quanta in 57% (4 out of 7, category [Energyqu]) of the cases. In contrast to cluster 1, however, all seven respondents in this cluster make statements that speak for indifferent imaginations (category [IndiffImage]): The respondents in this cluster are thus aware that photons cannot be equated with particles from an ontological perspective, but they imagine them as such in terms of shape.

Cluster 3: *Photon as a light particle.* The nine respondents in this cluster think of photons as components of light (category [ParticWave]) which underlines that students in this cluster gained rather mechanistic imaginations about photons. Although 44% (4 out of 9) reject a naïve idea of particles (category [RejectParticle]), at least dualistic ideas mixing different models seem to dominate among the students assigned to this cluster (cf. category [ParticWave]). Only 22% (2 out of 9) of the students in this cluster characterize photons as quanta of energy (category [Energyqu]).

6 Discussion

In physics education research, various studies into students' conceptions of quantum physics in general and about photons in particular, cf. (Greca and Freire 2003; Olsen 2002; Henriksen et al. 2018; Masshadi and Woolnough 1999; Sen 2002; Hubber 2006; Baily and Finkelstein 2010; Özcan 2015; Marshman and Singh 2017). Thereby, a cluster analysis approach has so far been used in various investigations: For example, Ireson extracted three clusters of students' conceptions about quantum physics from a questionnaire survey of physics students in Ref. (Ireson 1999). These clusters were identified with quantum thinking, intermediate thinking, and mechanistic thinking. Ireson (1999, p. 197) cites mechanistic thinking as the students' conception of the photon as a small, spherical entity, as one example. In contrast, he sees the notion of the photon as a "'lump' of energy transmitted into or out of the electromagnetic field" (Ireson 1999, p. 197) as an example of quantum thinking. These three levels in students' understanding of quantum physics between classical thinking and quantum thinking are reported in various articles concerning quantum physics education research, not only concerning the students' mental models on photons, cf. (Ireson 1999).

The types of students' conceptions about photons extracted from the results of our interview study developed by students introduced to quantum physics using the Erlanger concept and providing a QED model of the photon may be well associated with Iresons' clusters. The students of our cluster 1 "*Elaborated energy quantum notion*", for example, can be deemed to show quantum thinking in the sense of Ireson (1999): For instance, students of this cluster do not characterize photons as particles of light, but abstractly refer to them as energy quanta, even when the pupils are asked to describe and explain complex experiments (cf. Sect. 5). These results indicate that these students can be assigned to the functional type with respect to their understanding of (mental) models of photons, since their reasoning is based on a high degree of functional fidelity (cf. Ubben and Bitzenbauer 2022).

The students of cluster 2 "*Energy quantum in particle form*" can be assigned to Ireson's intermediate thinking (Ireson 1999): All students in this cluster explicitly mention that a conception of the photon as a spherical particle is not in accordance with experiments (cf. Table 2). Likewise, even no implicit statements suggest that these students think about photons as particles of light in a naïve sense. Nevertheless, indifferent conceptions can be observed among all students: although they seem to know that the particle concept leads to erroneous physical conclusions, the spherical concept is retained. The findings indicate that these students can be assigned to the dual type with respect to their understanding of (mental) models of photons, since their reasoning is based on both, a high degree of functional fidelity as well as a high degree of gestalt fidelity (cf. Ubben and Bitzenbauer 2022).

Cluster 3 "*Photon as a light particle*" can lastly be associated with mechanistic thinking (Ireson 1999): All nine students of the cluster reveal (naïve) particle conceptions of the photon (category [ParticWave]), but only 22% (2 out of 9) of the learners include abstract aspects toward energy quantum or excitation of the light field (category [Energyqu]), cf. Table 2. This observation indicates that these students can be assigned to the architectural type with respect to their understanding of (mental) models of photons, since their reasoning is based on a high degree of gestalt fidelity (cf. Ubben and Bitzenbauer 2022).

Taking all this together, the results of the cluster analysis reported in this article fit well with previous findings from physics education research. Nevertheless, drawing more valid and reliable conclusions about how teaching a QED model of the photon in introductory quantum physics courses can affect learners' conceptions of photons requires further investigation with appropriate instruments and larger samples. A first study in this respect revealed promising results (Bitzenbauer 2021c).

7 Conclusion

From research on quantum physics teaching and learning, we have deduced that introducing a QED model of the photon in favor of wave-particle duality might be suitable to circumvent known difficulties in learning quantum physics. Therefore, we conducted a first exploratory interview study to identify types of conceptions of the photon among students who were introduced to quantum physics using the Erlanger teaching concept on quantum optics and thereby were provided with a QED model of the photon from the beginning. The results of qualitative content analysis and cluster analysis show that widespread naïve particle notions of the photon were not observable in the majority of learners (clusters 1 and 2). Only the two students of cluster 3 seem to persist in classical mechanistic ideas. However, the extent to which the extracted types of students' conceptions could be context-dependent remains open. Specifically, the question arises whether the learners in clusters 1 and 2 have developed ideas about photons that are so stable and detached from naïve particle ideas that they do not occur even in contexts in which trajectory ideas and so forth are more easily triggered, for example, when one thinks of the double-slit experiment. The latter would constitute another strong argument for teaching the QED model of photons in introductory quantum physics classes.

References

Ayene M, Krick J, Damitie B, Ingerman A, Thacker B (2019) A holistic picture of physics student conceptions of energy quantization, the photon concept, and light quanta interference. Int J Sci Math Educ 17:1049–1070. https://doi.org/10.1007/s10763-018-9906-y

Baily C, Finkelstein ND (2010) Refined characterization of student perspectives on quantum physics. Phys Rev Phys Educ Res 6:020113. https://doi.org/10.1103/PhysRevSTPER.6.020113

Bitzenbauer P, Meyn JP (2020) A new teaching concept on quantum physics in secondary schools. Phys Educ 55(5):055031. https://doi.org/10.1088/1361-6552/aba208

Bitzenbauer P (2021a) Practitioners' views on new teaching material for introducing quantum optics in secondary schools. Phys Educ 56(5):055008. https://doi.org/10.1088/1361-6552/ac0809

Bitzenbauer P (2021b) Development of a test instrument to investigate secondary school students' declarative knowledge of quantum optics. Eur J Sci Math Educ 9(3):57–79. https://doi.org/10.30935/scimath/10946

Bitzenbauer P (2021c) Effect of an introductory quantum physics course using experiments with heralded photons on preuniversity students' conceptions about quantum physics. Phys Rev Phys Educ Res 17:020103. https://doi.org/10.1103/PhysRevPhysEducRes.17.020103

Bolderston A (2012) Conduction a research interview. J Med Imaging Radiat Sci 43(1):66–76. https://doi.org/10.1016/j.jmir.2011.12.002

Bormann M (1986) Das Schülervorverständnis zu Elektronen. In: W Kuhn (ed) Vorträge der DPG. Gießen, pp 227–232

Bronner P, Strunz A, Silberhorn C, Meyn JP (2009) Interactive screen experiments with single photons. Eur J Phys 30(2):345–353. https://doi.org/10.1088/0143-0807/30/2/014

Dehlinger D, Mitchell M (2002) Entangled photons, nonlocality, and Bell inequalities in the undergraduate laboratory. Am J Phys 70(9):903. https://doi.org/10.1119/1.1498860

Denis DJ (2020) Univariate, bivariate, and multivariate statistics using R: quantitative tools for data analysis and data science. Wiley, Hoboken, pp 327–345

Dür W, Heusler S (2014) Visualization of the invisible: the Qubit as key to quantum physics. Phys Teacher 52(8):489–492. https://doi.org/10.1119/1.4897588

Eshghi A, Haughton D, Legrand P, Skaletsky M, Woolford S (2011) Identifying groups: a comparison of methodologies. J Data Sci 9(2):271–291

Galvez E, Holbrow C, Pysher M, Martin J, Courtemanche N, Heilig L, Spencer J (2005) Interference with correlated photons: five quantum mechanics experiments for undergraduates. Am J Phys 73(2):127–140. https://doi.org/10.1119/1.1796811

Grangier P, Roger G, Aspect A (1986) Experimental evidence for a photon anticorrelation effect on a beam splitter: a new light on single-photon interferences. Europhys Lett 1(4):173–179. https://doi.org/10.1209/0295-5075/1/4/004

Greca IM, Freire O Jr (2003) Does an emphasis on the concept of quantum states enhance students' understanding of quantum mechanics? Sci Educ 12:541–557. https://doi.org/10.1023/A:1025385609694

Henriksen EK, Angell C, Vistnes AI, Bungum B (2018) What is light? Students' reflections on the wave-particle duality of light and the nature of physics. Sci Educ 27:81–111. https://doi.org/10.1007/s11191-018-9963-1

Henry D, Dymnicki AB, Mohatt N, Allen J, Kelly JG (2015) Clustering methods with qualitative data: a mixed-methods approach for prevention research with small samples. Prev Sci 16(7):1007–1016. https://doi.org/10.1007/s11121-015-0561-z

Hobson A (2005) Electrons as field quanta: a better way to teach quantum physics in introductory general physics courses. Am J Phys 73(7):630. https://doi.org/10.1119/1.1900097

Hobson A (2007) Teaching quantum physics without paradoxes. Phys Teacher 45(2):96. https://doi.org/10.1119/1.2432086

Hubber P (2006) Year 12 students' mental models of the nature of light. Res Sci Educ 36:419–439. https://doi.org/10.1007/s11165-006-9013-x

Ireson G (1999) A multivariate analysis of undergraduate physics students' conceptions of quantum phenomena. Eur J Phys 20(3):193. https://doi.org/10.1088/0143-0807/20/3/309

Jones DGC (1991) Teaching modern physics-misconceptions of the photon that can damage understanding. Phys Educ 26(2):93–98. https://doi.org/10.1088/0031-9120/26/2/002

Krijtenburg-Lewerissa K, Pol HJ, Brinkman A, van Joolingen WR (2018) Key topics for quantum mechanics at secondary schools: a Delphi study into expert opinions. Int J Sci Educ 43(3):349–366. https://doi.org/10.1080/09500693.2018.1550273

Marshman E, Singh C (2017) Investigating and improving student understanding of quantum mechanics in the context of single photon interference. Phys Rev Phys Educ Res 13:010117. https://doi.org/10.1103/PhysRevPhysEducRes.13.010117

Masshadi A, Woolnough B (1999) Insights into students' understanding of quantum physics: visualizing quantum entities. Eur J Phys 20(6):511–516. https://doi.org/10.1088/0143-0807/20/6/317

Mayring P (2000) Qualitative content analysis. Forum Qualitative Sozialforschung/Forum Qual Soc Res 1(2). https://doi.org/10.17169/fqs-1.2.1089

McGrath C, Palmgren PJ, Liljedahl M (2019) Twelve tips for conducting qualitative research interviews. Med Teach 41(9):1002–1006. https://doi.org/10.1080/0142159X.2018.1497149

Michelini M, Ragazzon R, Santi L, Stefanel A (2000) Proposal for quantum physics in secondary school. Phys Educ 35(6):406–410. https://doi.org/10.1088/0031-9120/35/6/305

Olsen RV (2002) Introducing quantum mechanics in the upper secondary school: a study in Norway. Int J Sci Educ 24(6):565–574. https://doi.org/10.1080/09500690110073982

Özcan Ö (2015) Investigating students' mental models about the nature of light in different contexts. Eur J Phys 36(6):065042. https://doi.org/10.1088/0143-0807/36/6/065042

Scholz R, Friege G, Weber KA (2018) Undergraduate quantum optics: experimental steps to quantum physics. Eur J Phys 39(5):055301. https://doi.org/10.1088/1361-6404/aac355

Sen AI (2002) Concept maps as a research and evaluation tool to assess conceptual change in quantum physics. Sci Educ Int 13(4):14–24

Stadermann HKE, van den Berg E, Goedhart MJ (2019) Analysis of secondary school quantum physics curricula of 15 different countries: different perspectives on a challenging topic. Phys Rev Phys Educ Res 15:010130. https://doi.org/10.1103/PhysRevPhysEducRes.15.010130

Strauß T, Maltitz MJ (2017) Generalising ward's method for use with Manhattan distances. PLoS ONE 12(1):e0168288. https://doi.org/10.1371/journal.pone.0168288

Thorn J, Neel M, Donato V, Bergreen G, Davies R, Beck M (2004) Observing the quantum behavior of light in an undergraduate laboratory. Am J Phys 72(9):1210–1219. https://doi.org/10.1119/1.1737397

Ubben M, Bitzenbauer P (2022) Two cognitive dimensions of students' mental models in science: fidelity of gestalt and functional fidelity. Educ Sci 12(3):163. https://doi.org/10.3390/educsci12030163

Wiesner H (1996) Verständnisse von Leistungskursschülern über Quantenphysik. Ergebnisse einermündlicher Befragungen. Physik in der Schule 34:95

Visible and Invisible Colours on the Edge of the Rainbow—A Remote Formal Activity on Electromagnetic Radiation

Martina Mulazzi, Nicola Ludwig, Enrico Rigon, Marco Stellato, Marco Giliberti, and Marina Carpineti

Abstract We designed a formal activity for high school students to answer the challenge of teaching the physics of electromagnetic waves with an inquiry-based approach. We focused on visible light, UV, near and far-infrared spectrum and on the response of matter to different wavelengths. The activity is inspired and connected to some informal learning aspects presented in one of the theatre performances of the Milan University project 'The Physics Show'. The activity is structured to be done also remotely, by maintaining an inquiry-based approach. We present and discuss both the didactic path and the possible strategies to train teachers and make them aware of how to drive students through this activity.

1 Introduction

Electromagnetic radiation is all around us and we constantly use it: we turn on the light, the radio and the television, we look at the sky, we perceive the warmth on our skin when it is exposed to sun, just to give some examples. Unfortunately, this familiarity has no counterpart in students' confidence in the nature and properties of electromagnetic (e.m.) radiation. For students it is also difficult to predict the response of matter to e.m. waves of different wavelengths, even in the case of the visible spectrum: concepts such as colour, summation of lights and vision are almost unknown (Martinez-Borreguero et al. 2013; Haagen 2014; Guesne et al. 1985; Chauvet 1996; Plotz and Hopf 2016). Things become much more complicated when students have

M. Mulazzi · N. Ludwig · M. Giliberti · M. Carpineti (✉)
Dipartimento di Fisica 'Aldo Pontremoli', Università degli Studi di Milano, 16 Via Celoria, 20133 Milano, Italy
e-mail: marina.carpineti@unimi.it

E. Rigon
Liceo Scientifico Statale 'G.B. Grassi', 1 Via B. Croce, 21047 Saronno, VA, Italy

M. Stellato
Liceo Scientifico Statale 'G. Galilei', 119/A Via San Francesco, 24043 Caravaggio, BG, Italy

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_14

to predict the behaviour of radiation that is invisible to the human eye, such as ultraviolet (UV) and infrared (IR). Recently, many devices that detect this radiation, have become available at moderate prices but students who use them, either for fun or at school, often are not able to interpret the images correctly (Emigh et al. 2014; Akdeniz and Sadoglu 2015; Besson 2009; Viennot and Hosson 2014; Millar 1994; Neumann and Hopf 2012; Libarkin et al. 2011). Starting from the opportunity to use cameras sensitive to UV and IR at school and the difficulties of students in understanding their outcomes, we designed an educational path on electromagnetic radiation for 12th and 13th-grade students that take them through the different behaviours of e.m. waves when the wavelengths are varied.

The objective of our work is to enable them to deal with e.m. radiation in the wavelength range from UV to far IR and to predict behaviour when such radiation interacts with matter. The path starts with visible light that has many familiar aspects but also many unexpected ones. Students face their difficulties when they try to define the concept of colour or when they try to predict what happens when lights of different wavelengths are mixed. What is learnt for visible light is then applied to other spectral bands, as will be explained later.

Every different subject is anticipated by an engaging issue that students will be able to solve at the end. To reach this goal, students are involved in many different activities, from experiments to solutions to problems, reading and demonstrations. Some informal elements and open questions come from a science theatre play, entitled 'Light from the Stars'[1] that the students should attend before this activity. The show is about electromagnetic radiation, multispectral observation of the universe and finally, presents a subtle criticism of a superficial popularization of science. The play is a project of the University 'La Statale' of Milan for science communication, called 'The Show of Physics'[2] (Website: http://spettacolo.fisica.unimi.it/), (Carpineti et al. 2006, 2011).

The activity was originally projected for the use at school, but, due to the COVID-19 emergency, it has been transformed into an online educational path, to make it possible also for home-based students to participate in an inquiry-based (Bybee et al. 2006) project. Videos of the show have been inserted to account for the impossibility to attend directly. Some experiments that cannot be done at home have become filmed demonstrations, but there are still many experiments that students can make at home and observations of daily phenomena that students may make to increase their awareness of the problems. The new activity requires more independent work from students and some issues that they may face following the educational path have emerged during a first test done with university students attending a course on preparation of didactical experiences. In particular, it has become clear that teachers have to play a key role in guiding students through the various steps. Their role is particularly critical as they have to provide opportunities for discussion among students on their questions and issues and to foster their understanding, despite the hostile framework of remote participation. As a consequence, we are implementing

[1] Italian title 'Luce dale Stelle'.

[2] Italian title 'Lo Spettacolo della Fisica'.

a teachers' guide to train them in the use of the educational path, with a special focus on how to help students to overcome conceptual issues and with hints on how to stimulate discussions and sharing of doubts. In this work we first describe the format of the activity and its contents, then we give some examples of the strategies adopted to promote an independent use of the activity by teachers and possibly their autonomous development of similar didactical paths. Finally, we give detailed examples of the teachers' guide and we report the results of the first tests done.

2 The Inquiry-Based Educational Path

The educational path was co-designed together with high school teachers. It is organized into three activities, each dealing with a different spectral range. All the activities can be performed in two steps to allow an interlude in which students may expose their doubts to each other and discuss with teachers. In all the activities students see demonstrations, watch videos of the show, 'Light from the Stars', perform exercises, solve problems, read and study texts.

- The first activity is devoted to the visible spectrum and is entitled: 'What do human eyes see?' It deals with the interaction of light and matter of varied size and composition that gives rise to phenomena such as diffusion, absorption and transmission. Special attention is given to the vision model, to the physics of colour and to additive and subtractive mixing of light and pigments. There is evidence that students have a difficulty in relating the three elements involved in the process of colour vision: visible light source, object and human eye. They often think that colours are a property of only one of these three elements (Guesne et al. 1985).
- The second activity is devoted to the near-infrared (NIR) and UV spectral ranges, the wavelengths closest to the visible range and is entitled 'Seeing with different eyes'. Students have to imagine how eyes, sensitive to different radiation from the visible, could see the world around us. In this attempt they are driven towards the definition of spectral interaction coefficients: absorbance, reflectance and transmittance and their relations. They define radiation intensity and are asked to draw transmittance, absorbance and reflectance spectra of different materials.
- The third activity is about far-infrared (FIR) radiation, often named thermal radiation and is entitled 'Emission and Spectra'. It deals with thermology and introduces students to the Stefan-Boltzmann law, the Wien displacement law and heat transfer. As will be explained in the following, the use of thermal cameras for the filmed demonstrations allows us to present with an inquiry-based approach the fundamental concepts of blackbody radiation and to introduce the phenomena in a qualitative way.

3 Teachers' Training

Students perform their activities autonomously, but online forms are not enough for full comprehension among students. Moments with teachers, where they interact with students and support their learning from an IBSE (Inquiry-Based Science Education) (Rocard 2007) perspective, are necessary and teachers are expected to give hints that can drive students to find the solutions to their doubts. Presently, the path has been tested with some university pupils attending a course on preparation of educational experiments and with 47 high school students together with their teachers. In both cases, the participants were driven by ourselves, who are the authors of this activity. However, the idea is to pass the project to high school teachers. To make teachers confident with the task to follow students through the path, it is extremely important to train them properly.

The strategies we are adopting are the following:

(i) Teachers have to try the path as if they were students, to test personally the difficulties they may encounter.
(ii) The goals of the activity, the learning intent and the reasons that have inspired the choices made to plan the educational path are shared with teachers. This point is fundamental to help them to become autonomous in the management of the activity with students.
(iii) Teachers are warned of some possible students' conceptual issues. The activities try to solve those issues which are described in the research literature.
(iv) Teachers are given suggestions for and provided with, further readings. They can be either paper chosen in the didactic literature where the typical difficulties students find in approaching some subjects are discussed, or papers to learn more about an argument presented in the path. This second category may include some deepening texts written on purpose by us.
(v) Finally, we suggest experiments where easy-to-find objects are used, in order to simplify the task of the teachers with respect to the experimental part.

All these points are implemented in a teachers' guide for each activity which leads teachers through the learning path and, in particular, through the various form questions, exercises and concepts. The guide is a tool for teachers to make them aware of the issues related to the form activities. Figure 1 shows an example taken from the second activity where the learning goals are presented.

The main part of the guide consists of some hints for a discussion with students, the activity exercise solutions and some formal explanations of those phenomena that are presented in the activities but not properly described. This part has been completed after the first experimentation with university students and with high school students in autumn 2020 when some critical points and hints have been added, in order to guarantee better learning experience for students and teachers as well. The last part of the guide contains appendixes with calculus, operational suggestions and a bibliography to deepen the topics dealt with in the activity.

In the following, we present some examples of the activities performed with students and the corresponding contents of the teacher's guide.

General Goals	Content Goals
General Goals The learning path is designed in order to stimulate students to: • understand and draw diagrams; • graphically represent a coefficient trend as the wavelength varies; • show in a diagram experimental data and phenomena; • make predictions about a certain physical phenomenon not yet experienced; • deduce rules from what has been observed and experienced.	Content Goals The educational path presents students the following topics: • Electromagnetic waves: definition and properties • Frequency and wavelength relationship • Radiation-matter interaction and spectral interaction coefficients: transmittance, reflectance, absorbance • Properties and characteristics of UV and near infrared radiation • Electromagnetic spectra and transmittance spectra • Division of the electromagnetic spectrum into spectral bands according to the wavelength • Power (flux) and intensity of an electromagnetic radiation • Radiation-matter interaction energy conservation • Functioning of detectors operating in bands differente from the visible one

Fig. 1 Activity II goals from the teacher's guide

3.1 *Activity I Examples*

For students

The question 'How do you describe colour?' is the leitmotiv of the first activity. Many experiments are presented to give the participants new cues to answer it. During the experiences, participants can learn about the interaction between visible radiation and bodies (diffusive reflection and absorption), about eye physiology and about additive and subtractive mixing. The purpose is to lead the participants to investigate the real nature of colour and to create a proper vision model.

In one of the activities, the participants are involved in observing some sheets of paper that have different colours in white light (white, red, orange and purple) as they appear when illuminated by red, green and blue monochromatic light and when watched through filters of the same colours. In Fig. 2, a piece of paper that

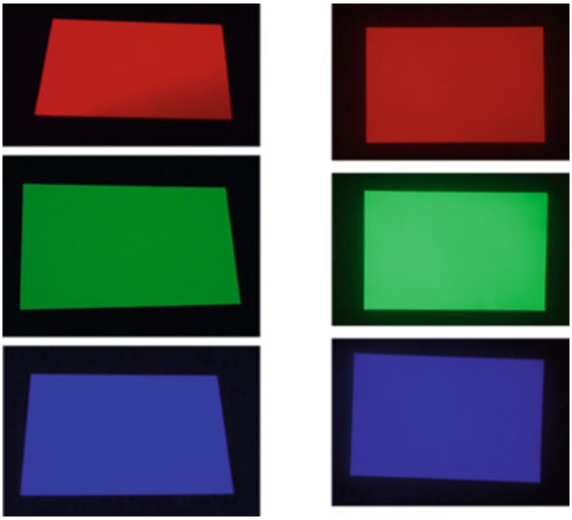


Fig. 2 A paper that appears white in normal light conditions is illuminated by a red, green and blue light (in the first column) and it is seen through a red, green and blue filter (in the right column). It appears of the same colour of the light/filter used

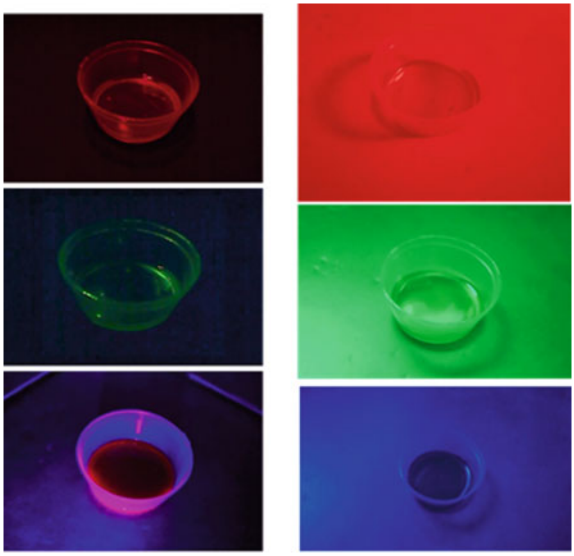


Fig. 3 A coloured fluid is illuminated by red, green and blue light (left column) and it is seen through a red, green and blue filter (right column). The fluid appears of the same colour as the light/filter used, with exception of the blue light and filter where it appears, respectively, red and black. Notice that the background is not the same in all the pictures as it was varied depending on photographic needs

looks white in normal light illumination is shown. No differences can be appreciated between the coloured light illumination and the vision through the coloured filters.

After that, participants see the image shown in Fig. 3. It represents various images of the same coloured fluid in a transparent container under different conditions. On the left column, there are pictures of the fluid illuminated by a monochromatic red, green and blue light. On the right column, the pictures of the fluid watched through a red, green and blue filter. Participants are asked what colour they think the fluid is in white light conditions. This situation is different from the one that participants have previously met because the fluid is fluorescent under blue light. Therefore, they are actively engaged in a new phenomenon, which they may not know and are stimulated to ask themselves questions about it. This way to proceed is typical of this didactical path and has the objective to force students to formulate hypotheses on the basis of the acquired knowledge and to either validate or reject them, after comparing their prediction to the outcome of the experiments.

For teachers

The question 'How do you describe colour?' is asked at the beginning and at the end of the first activity and also at the end of the entire learning path. Based on our experience with the questionnaires filled by students, we noticed that the percentage of those who described the colour as an interaction between light, body and sensor was almost doubled with respect to the beginning. However, some of them still thought the colour is simply a light or a body's property also at the end of the entire path. These results guided us to add a warning in the teacher's guide about the possible difficulties of students in understanding the colour vision model. Students understand the colour as an eye perception/interpretation of the visible radiation (28%), but it

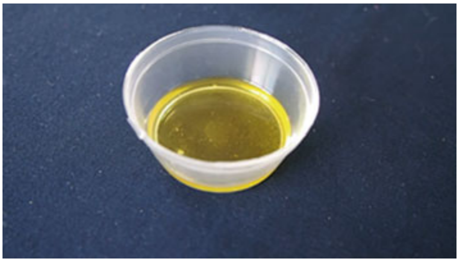


Fig. 4 The fluid is yellow under white light

Light as an electromagnetic wave

The entire learning path deals only with the wave nature of light, nothing is intentionally said about its corpuscular nature.

Fig. 5 Activity I teacher's guide part

is not clear if they recognize the importance of radiation-body interaction in the process.

In the guide, there are also hints for class discussion. An example is the fluorescence phenomenon cited above. Teachers can find clues and experiments in case they want to formally explain the fluorescence to their students. In particular, the guide contains a document where the phenomenon is briefly explained at a high school level that teachers can pass to their students as a supplementary worksheet. The guide also contains some practical advice if the teacher wants to repeat the activity experiments in class, gives the solution to the exercises and answers to questions left without answer. For example, it reveals that the mysterious fluid shown in Fig. 3 is olive oil (see Fig. 4).

The guide also gives some information to teachers about our formal physical choices, an example is in Fig. 5.

The guide of activity I has a special Appendix dedicated to make teachers aware of possible problems in doing the learning path for students with dyschromatopsia (eye alteration of colour vision). The Appendix contains some suggestions on how to deal with this issue and to guarantee colour-blind students the same opportunity to take part to the learning path.

3.2 Activity II Examples

For students

The second activity aims to help students to understand some properties of the interaction of e.m. radiation and matter, by showing them how the world would appear when watched with different eyes. For example, some studies (Plotz and Hopf 2016; Emigh et al. 2014) highlight students' difficulties understanding that transparency and opacity are not absolute properties of matter (Besson 2009) but depend on the wavelength of the e.m wave interacting with them. At first, the activity tries to make students figure out that there is invisible radiation all around us. This is achieved by engaging them in a simple and quick experiment that they can do at home with a cell phone camera and a television remote control. The camera is able to see a bright light from the remote's sensor, when a button is pressed, which is otherwise invisible to human eyes. This is an example of near-infrared radiation detection. Students are asked to apply to the present case the vision model found for visible radiation in the first activity and determine how three elements interact with each other: source, object and detector. That allows for easy introduction of the three spectral coefficients: transmittance T, absorbance A and reflectance R.

Thanks to some experiments, videos, images and reasoning, students are led to find out autonomously the definition and meaning of these coefficients. For example, students have many cues to find an informal definition of the transmittance coefficient. It is introduced as the fraction of the incident radiation intensity that is transmitted by a body. Then, the behaviour of some materials is shown to the students. In particular, the particular case of a plastic slab that appears very different in the visible and near-infrared bands is shown. As Fig. 6 shows, the slab appears opaque to our eyes and transparent to a near-infrared camera. The image is from the theatrical play 'Light from the Stars' (Website: http://spettacolo.fisica.unimi.it/) and it is an example of how informal elements are employed in the online activities.

Fig. 6 Scene from the theatrical play 'Light from the Star'. On the top screen, there is the image captured by a near-infrared camera where the black panel disappears completely

Transmittance (T):

$$T(\lambda) = \frac{\Phi_t(\lambda)}{\Phi_i(\lambda)} \qquad (1)$$

Where $\Phi_i(\lambda)$ e $\Phi_t(\lambda)$ are respectively the radiation flux (also called radiation power) incident on the object surface and emerging (transmitted) from the object opposite surface, observed at a certain wavelength and measured in Watts.
Given the formula:

$$\Phi(\lambda) = I(\lambda) \cdot A \qquad [W \cdot m^2] \qquad (2)$$

where $I(\lambda)$ it is the spectral radiation intensity and A is the irradiated object surface, so the trasmittance equivalence can be written as in equation 1:

$$T(\lambda) = \frac{I_t(\lambda)\, A_t}{I_i(\lambda)\, A_i} \qquad (3)$$

if the considered object areas, at the radiation incidence and exit point, have the same size, the A_t and A_i terms elide, so to get:

$$T(\lambda) = \frac{I_t(\lambda)}{I_i(\lambda)} \qquad (4)$$

Fig. 7 Activity II teacher's guide

For teachers

Activity II presents some new physical quantities to students. In order to make them think and reason in complete autonomy, definitions are found by students in a qualitative, or informal, way. However, it is important that they learn how to express concepts introduced in the activity in a mathematically correct way. Therefore, teachers can find in the guide the formal definitions of the spectral coefficients A, R and T, according to the formalism used in the activity but also some insights into the formulae. An example is shown in Fig. 7 for transmittance spectral coefficient T. The example shows not only the mathematical definition of T, but also the mathematical steps to derive it.

Furthermore, the guide recalls some images and experiments from the activity and explains them in detail. It also gives some advice for teachers who want to repeat the near-infrared and ultraviolet experiments with their students.

The experimentation with high school students underlined students' difficulties in drawing and understanding graphs. Therefore, we added some specific points in the guide, to make teachers aware of specific issues. In the guide, teachers can also find some additional exercises, based on possible conceptual problems which they can solve together with students, or leave as homework.

3.3 Activity III Examples

For students

During the activity, students will try to answer the question 'What does a thermal camera measure?' They can try to answer it thanks to some experiments' images, videos and calculation exercises presented to them in the online form. Furthermore, they can apply what they have learnt from previous activities and some common-sense knowledge, for example, the fact that the thermal camera is commonly used to measure body temperature from a distance.

Students are engaged when they find a discrepancy between real temperature of heated metal objects and that measured using the false-colours palette of the thermal camera (Ludwig and Carpineti 2020). Metals have a very large reflectivity value and consequently low emissivity. In fact, these coefficients are related by the Kirchhoff's laws for thermal radiation, shown in Eqs. (1) and (2).

$$A(\lambda) + R(\lambda) + T(\lambda) = 1 \tag{1}$$

$$A(\lambda) = \varepsilon(\lambda) \tag{2}$$

Transmittance is negligible for metals, so the Kirchhoff's law can be rewritten as in Eq. (3).

$$R(\lambda) + \varepsilon(\lambda) = 1 \tag{3}$$

In Fig. 8 there are images shown in the online form of different heated materials (a coffee pot on the left and pieces of various materials, among which a metal plate, on the right) where it clearly appears that for metals the colours of the images are not representative of their temperatures.

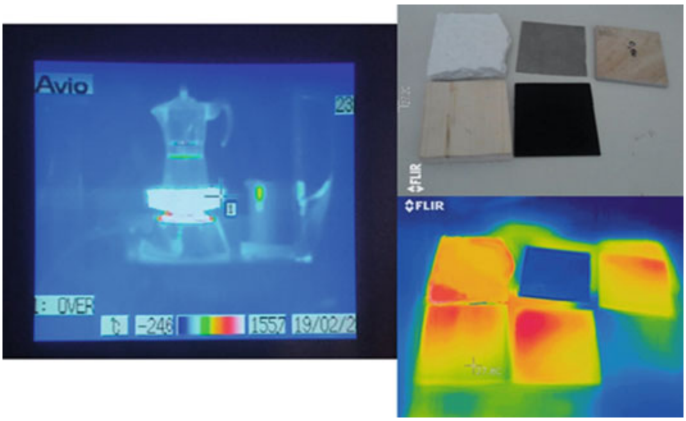
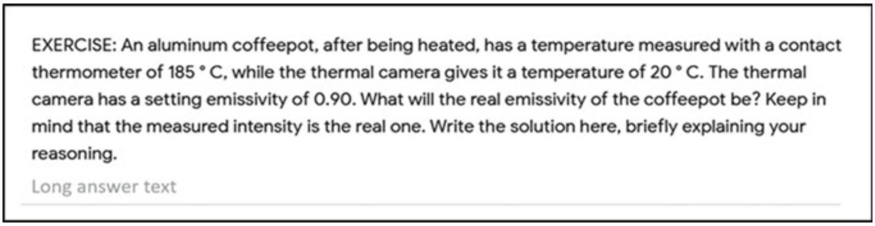


Fig. 8 Thermal images of different materials. Based on the palette reference colour, the coffee pot seems to be at room temperature, while its temperature is approximately over 155.7 °C, the maximum value shown in the legend. The various materials on the right are all at the same temperature of approximately 60 °C and are shown both in the visible (up) and as seen by a thermal camera (down). The metal sheet is the one that looks colder than the others, based on the palette colours of the thermal camera


EXERCISE: An aluminum coffeepot, after being heated, has a temperature measured with a contact thermometer of 185 ° C, while the thermal camera gives it a temperature of 20 ° C. The thermal camera has a setting emissivity of 0.90. What will the real emissivity of the coffeepot be? Keep in mind that the measured intensity is the real one. Write the solution here, briefly explaining your reasoning.

Long answer text

Fig. 9 An exercise in the online form

In the activity, there is also some mathematical exercise, as the one in Fig. 9 from the online form, which asks students to calculate the emissivity coefficient of aluminium.

Furthermore, the activity introduces students to the ideal body emission spectra, thanks to the 'Blackbody Spectrum' applet provided by the 'PHET Colorado' website (PHET Colorado applet website: https://phet.colorado.edu/sims/html/blackbody-spectrum). The activity aims to make students understand that not just inanimate, artificial, or radioactive bodies emit radiation but all bodies do, in the form of thermal radiation (Plotz and Hopf 2016; Millar 1994). By using the application, students become aware that the body temperature and the emission peak wavelength are interrelated quantities. Students are then given either the temperature or the emission peak wavelength of various bodies such as a blue gigantic star, a person, a light bulb, a mosquito repellent and the cosmic background radiation and are asked to find the other information through the application. Students draw the data in a graph with temperature and peak wavelength, respectively on the axes and the graph returns an inverse proportionality between the two quantities, which students can easily recognize. Therefore, they can autonomously find the temperature-emission wavelength peak mathematical relation, i.e. the Wien's displacement law, in Eq. (4).

$$T = \frac{2.8 \times 10^{-3}[\mathrm{m\,K}]}{\lambda_{\mathrm{peak}}} \tag{4}$$

The applet also gives the value of the area under the emission curve which is the total intensity emitted by an ideal body. Students can use it and a diagram generator software, as Excel or gnuplot (Website: http://www.gnuplot.info), a programme for the mathematical functions representation, to find the relation between the total intensity emitted by a body and its temperature, i.e. the Stefan-Boltzmann's law in Eq. (5). In the equation, σ represents the Stefan-Boltzmann's constant.

$$I_{\mathrm{tot}} = \sigma T^4[\mathrm{W/m^2}] \tag{5}$$

In the final part of the online form, students face an experiment with the thermal camera shooting an aluminium cube heated at about 80 °C with a hole on one side, as shown in Fig. 10. The thermal image shows that the cube is apparently at room

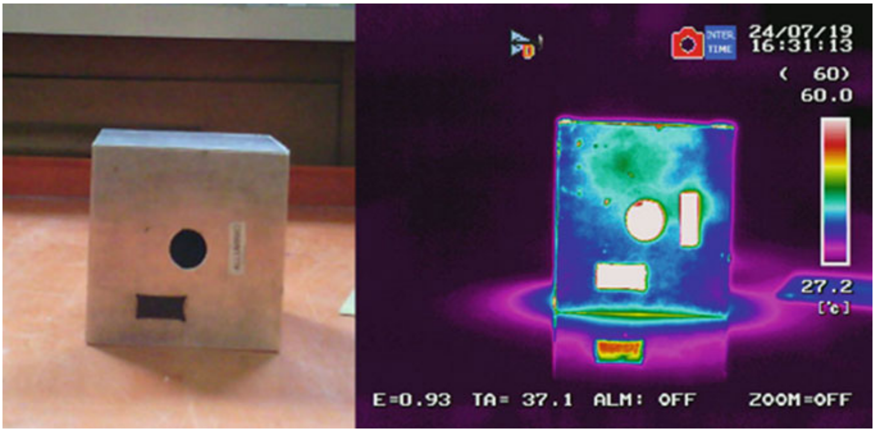


Fig. 10 Visible (on the left) and thermal (on the right) image of an aluminium cube with a hole on one side, heated at approximately 80 °C. The black and white rectangles in the visible image are pieces of electrical tape, which are used as indicators of the real cube temperature. This is possible because the electrical tape's emissivity is high (> 0.9), so the thermal camera returns its correct temperature value

temperature, which is no longer surprising because students know that aluminium has a low emissivity. On the contrary, the hole's colour reveals the real temperature. The experiment is extremely engaging and can be used with students as a real example of blackbody emission.

For teachers

The activity aims to define the properties of bodies' emissions and the physical phenomena involved. We choose the thermal camera as a tool to achieve our goal. Of course, the thermal camera can be used to study heat diffusion phenomena (Carpineti et al. 2019) but teachers have to pay attention to the emissivity of investigated material before any experimentation.

The online form shows some thermal images to students, allows them to think about different behaviours of ideal and real bodies and introduces them to the emissivity spectral coefficient (ε). In the guide teachers can find some information about thermal cameras so that they can become familiar with the principle of operation and the role of the emissivity setting in the measurement.

Students are asked the question 'What does the emission of bodies depend on?' both after the exercise shown in Fig. 9 and at the end of the path. The analysis of students' answers highlighted the need that teachers clarify to students some concepts that the online form only outlines. In particular, despite students seeming to have improved their understanding, it is not clear that they really internalized the differences between ideal and real cases. Therefore, it is important that teachers consolidate students' knowledge about this topic during the final discussion. In the guide, we added some suggestions, for example, that to recall some experiments and images seen in the online form, as the one of the blackbody cubes. Some high school students who tested the path told us to be very impressed with this blackbody qualitative experiment.

In the online form students can see and work on the emission spectra, but the Planck's formula is never properly presented. Teachers who are interested in deepening this topic with their students could find in the Appendices of the guide some exercises in which they can use the Planck's formula to obtain the Wien's displacement law and the Stefan-Boltzmann's law. The exercises use the same mathematical formalism of the online form. They were deliberately avoided in the activity because they need some mathematical tools such as derivatives and integrals, which students may not already know. However, the exercises could help students to understand the physical meaning of derivatives and integrals. Teachers can make connections between what students saw in the online form and the mathematical tools of the exercises.

4 Conclusions

The first experimentation with high school students gave positive results. Many students were interested in the activity topics. Many were active, responsive and curious. Students particularly appreciated the use of images, videos and online applications, thanks to which they better understood the topics and the concepts.

They particularly appreciated the teaching method used, namely the inquiry-based methodology (Rocard 2007). They enjoyed the engaging parts and the fact that they could autonomously and freely make hypotheses about the observed phenomena and predict the physical models and the experimental outcomes. They also appreciated the fact that their hypotheses could be rejected, just as in the scientific research method, so they could have a taste of the real physics research.

Some students said that the activity method was very different from the experimental methods they used at school. Even though the majority of students would have preferred an activity performed in the classroom and laboratory, they were satisfied with the educational path.

Furthermore, some teachers participated in the experimentation. They described to us positive impressions by their students who attended the activity. Some of them even tried the didactical path on their own and gave us positive feedback and even some suggestions as to how to improve the activities. One of them will try in the future to create a similar but shorter educational path on electromagnetic radiation, made by an online form for students that will be the basis for a classroom discussion.

Remote learning can be inquiry-based with the right tools and a proper teachers' training. The online forms alone are not enough for a proper student's knowledge internalization. Our teachers' guides are intended to make teachers aware about students' issues and difficulties but also to give them the competencies to manage remote activities complementary to the educational path by maintaining an inquiry learning perspective. Furthermore, our educational path can provide a partial solution to some remote teaching obstacles, such as the lack of students' active participation, involvement and motivation during remote classes. It gives teachers cues on new approaches and ways to interact with students, without falling into a one-directional teaching method. In a remote inquiry, students can work more independently than in a laboratory activity, so teachers need to know when to intervene. It is very important to guarantee that students have time to think for themselves without teacher's suggestions. Therefore, our activity is built in such a way that teacher intervenes only in precise moments, namely at the end of each half of the three activities. Consequently, the teacher has to provide opportunities for discussion among students on their questions and issues and has to foster their understanding, always in an inquiry-based perspective.

In conclusion, the results of the experimentation gave us the idea that it is possible to adapt an inquiry-based educational path to be performed remotely. The majority of high school students had positively internalized the main concepts and were motivated by the activities. Even teachers who attended the learning path were positive about it and curious about the method used. Our future purposes are to test the educational path with other students and teachers, to lend teachers our online forms and teacher's guides in order to let them independently conduct the educational path with their students and to have feedback from it.

Author Contributions M. Carpineti and M. Giliberti conceived the study; M. Mulazzi, M. Carpineti, N. Ludwig and M. Giliberti designed the study; M. Mulazzi conceived and assembled the forms under the supervision of M. Giliberti and M. Carpineti; M. Mulazzi and M. Carpineti analyzed results and wrote the paper; N. Ludwig, M. Stellato and E. Rigon helped in realizing the material used for the educational path. All the authors contributed to the paper.

References

Akdeniz A and Sadoglu G (2015) J Stud Educ 5(3)
Besson U (2009) Eur J Phys 30:995
Bybee RW, Taylor JA, Gardner A, Van Scotter P, Carlson J, Westbrook A, Landes N (2006) The BSCS 5E instructional model: origins and effectiveness, and application. BSCS Colorado Springs, Colorado
Carpineti M, Cavallini G, Giliberti G, Ludwig L, Mazza C, Perini L (2006) Il Nuovo Cimento della Società Italiana di Fisica B 121:901–911
Carpineti M, Cazzaniga L, Perotti L, Giliberti M, Cavinato M, Ludwig N (2019) Can J Phys 97(9):1019–1026
Carpineti M, Cavinato M, Giliberti MAL, Ludwig NG, Perini L (2011) JCOM 10
Chauvet F (1996) Eur J Teach Educ 12(2):121–136
Emigh PJ, Passante G, Shaffer PS (2014) Student understanding of blackbody radiation and its application to everyday objects. In: 2014 Proceedings conference on physics education research 2013 (Portland, OR) pp 137–140
Guesne E, Driver R and Tiberghien A (1985) Children's ideas in science. Open University Press, Milton Keynes, pp 10–32, Chap. 2
Haagen C (2014) Proceedings international conference on GIREP-MTPL 2014 (Palermo) Fazio C, Sperandeo Mineo RM (eds) pp 251–258

Libarkin J, Asghar A, Crockett C, Sadler P (2011) Astron Educ Rev 10:49–60
Ludwig N and Carpineti M (2020) Phys Educ 55(2)
Martinez-Borreguero G, Pérez-Rodríguez ÁL, Suero-López MI, Pardo-Fernández PJ (2013) Int J Sci Educ 35(8):1299–1324
Millar R (1994) Public Underst Sci 3(1):53–70
Neumann S, Hopf M (2012) J Sci Educ Technol 21(6):826–834
Plotz T, Hopf M (2016) Int J Sci Math Educ 4:447–459
Rocard MO (2007) Science education now: a renewed pedagogy for the future of Europe. European Commission. Community Research [Online] Available at: https://www.eesc.europa.eu/resources/docs/rapportrocardfinal.pdf
Viennot L, de Hosson C (2014) Int J Sci Math Educ 37:1–30

Introducing General Relativity in High School: A Guide for Teachers

Adriana Postiglione and Ilaria De Angelis

Abstract Introducing Modern Physics represents an increasingly urgent need, toward which physics education concentrates many efforts. In order to contribute to this attempt, at the Department of Mathematics and Physics of Roma Tre University in Rome, we focused on the possibility of treating General Relativity (GR) at high school level. We started with an interactive activity addressed to students that exploit the rubber sheet analogy (RSA) to show various phenomena related to gravity using the concept of space–time. Then, having verified its effectiveness, we began to include it among the initiatives the Department carry for high school teacher professional development, with the explicit aim of making them capable of carrying on the activity autonomously in the classrooms. In this paper, we analyze the teacher training approach we realized, and all the materials developed.

1 Introduction

Among the various actions physics education research is carrying on in recent years, introducing Modern Physics in high school certainly stands out. The urgency of this effort is evident also in Italy, where the Ministry of Education itself added Modern Physics topics in the program directions provided to teachers starting from 2010 (Ministero dell'Istruzione 2010).

In order to contribute to this collective effort, at the Department of Mathematics and Physics of Roma Tre University, we started to work on the possibility of talking about General Relativity (GR) with a non-expert public. We began with groups of people of various ages (adults, teenagers, children), we then involved groups of high school students and we finally turned to high school teachers, with the ambitious aim of making them confident and autonomous in treating GR in their classrooms.

A. Postiglione (✉) · I. De Angelis
Dipartimento di Matematica e Fisica, Università degli Studi Roma Tre, Via della Vasca Navale 84, 00146 Roma, Italy
e-mail: adriana.postiglione@uniroma3.it

INFN Sezione di Roma Tre, Roma, Italy

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_15

At the end of our study, we obtained a training method that provides teachers with the right tools and guidelines, which already proved to be well received by them. In this paper, we describe the training method we developed and the steps that led us to build it.

The model we used is the popular rubber sheet analogy (RSA), which compares the Einsteinian space–time to a rubber sheet that stretches under the weight of a mass. Using marbles and balls thrown on the sheet, it is possible to simulate the gravitational attraction of several astrophysical objects. This analogy has been studied for years in physics education research, proving to have weaknesses and critical points (Kersting 2019, 2018; Price 2016; Gould 2016) but also to be effective and potent in many cases (Pössel 2017; Farr et al. 2012; Baldy 2007; Thorne 2009; Postiglione and Angelis 2021a).

For this reason, at the Department, we decided to build a 1.8 m diameter circular structure supporting a lycra sheet that could show the RSA. Then, we started to use it with marbles and balls of different weights, with the aim of reproducing various phenomena related to gravity: from Kepler's laws to space exploration, from gravitational lensing to black holes. Our intention was to build an interactive activity that would allow the audience to first-hand experience the phenomena we wanted to deal with since this kind of activity proved to be effective and engaging in learning (Freeman et al. 2014; Prince 2004; Hake 1998).

Once we had an idea of what we could do with the structure, we started testing it with a varied audience, initiating our preliminary study, which eventually led us to develop a real teachers' professional development initiative.

The remaining paper is organized as follows. In Sect. 2 we retrace the preliminary study we conducted, focusing on different audiences. In Sect. 3 we present the approach we tested in presence of teachers; in Sect. 4 we illustrate some first reactions to our training activity and in Sect. 5 we present our conclusion and some future developments of our work.

2 The Preliminary Study

Since our final aim consisted in structuring a teachers' professional development course involving the use of the RSA, we needed to know as much as possible about the reactions of the audience to it: their understanding, feedback, degree of involvement, the possible birth of misconceptions and the best way to solve them. For this reason, we started our study with a varied audience, before turning to high school students and teachers.

2.1 Experimentation with a Varied Audience

Our test with a varied audience (adults, teenagers, children) was conducted during the public outreach events that take place at the Department three times a year. During these events, the Department opens its doors to the public and University students, researchers, and professors show different experiments and scientific activities. The atmosphere is typically very informal, and participants can move freely between the proposed activities, asking questions and interacting with scientists.

In this context, the activity we carried out with the rubber sheet dealt with a variety of laws and phenomena (the motion of planets around stars, binary systems, black holes, gravitational lensing, time dilation) and was very well received: people of different ages (from 3 years old children to adults) were intrigued by the structure and tried to arrange weights on the sheet and throw marbles in order to see their behavior. Moreover, several people asked questions also related to complex topics such as black holes or gravitational lensing.

From these tests, we thus concluded that the playful and interactive aspect of our activity represents its most relevant strength since it attracts and intrigues people, who are then willing to listen to further insights provided through videos and images. Moreover, we noticed that a significant part of the public's curiosity came from discovering the orbit of planets or space probes rather than just the exotic topics like black holes. This means that the rubber sheet could also be used effectively to talk about classical gravity and not just GR.

2.2 Experimentation with High School Students

The experimentation with high school students involved 14 Italian high school different classes and two mixed groups of students coming from different high schools, for a total of about 400 students.

We initially used our rubber sheet with the participants of a physics summer school. They were selected taking into account their interest in physics and their previous grades, and they had all already attended the third year of Italian high school (meaning that they already treated the Newtonian description of gravitational force with their teacher). After a short activity in which we explained to them the basics of the RSA, the space–time structure was placed in a dedicated room that we could easily access with them. In the following days, we often returned to the space–time simulator, asking participants to experience different phenomena and try to explain them. In this way, we were able to closely follow the students' understanding of the topics, and we were able to calmly reason about their misconceptions and the way to overcome them.

After the experience with the summer school, we decided to define a more structured activity lasting an hour and a half that could deal with several topics related to gravity: Kepler's laws, gravity assist, binary systems, gravitational lensing, and black holes. In order to do that, we decided to validate it with classes of different years (one class for each of the five years of the Italian high school) thanks to the collaboration of a teacher who has been working with the Department for years. In this way, we investigated the reaction of participants of different ages.

Once we had structured the activity, we began to verify its effectiveness by involving other schools, reaching more than 200 students in nine classes. Before and after the activity we administered questionnaires to the participants, in order to explore their reactions and comprehension of the different topics addressed. As it will be clear in the following of this paper, the results of such tests were precious in order to build an effective teachers' professional development activity, so we will report their essential aspects; the complete analysis of the questionnaires can be found in Postiglione and Angelis 2021a.

2.3 Experimentation with High School Teachers

In addition to discussing with the teachers who accompanied their classes during the experimentation with students, in the same period of the tests described so far, we carried on a parallel experimentation with high school teachers. In particular, we involved the participants in the teachers' professional development course that was taking place at the Department, and which was focused on Modern Physics. The participants were about 25 and came from schools in Roman area. During the course, we showed the teachers our space–time simulator and the activity-related, in order to train them on GR. The reactions were very positive: the teachers demonstrated to be curious and interested; some of them also claimed that the RSA provides a wonderful way to finally visualize Kepler's laws. When asked explicitly, they replied that they would be very interested in including the activity in their teaching.

2.4 Results from the Preliminary Study

The experimentation with different audiences convinced us that our activity based on the use of the rubber sheet could really be useful for teachers to deal with gravity in their classrooms. In fact:

- Our use of the RSA was effective in talking about gravity, as demonstrated by the results of the questionnaires administered to high school students (Postiglione and Angelis 2021a). The phenomena treated were visualized better, understood, and remembered longer compared to a traditional treatment.
- The activity proved to engage and entertain the participants, who were thus more willing to ask questions and interact.
- High school teachers demonstrated to be interested in including the activity in their teaching.

- Although the RSA could reinforce misconceptions and conceptual mistakes related to gravity, they could be also easily overcome if addressed explicitly. Therefore, teachers had to be prepared to know and react to these aspects.

3 The Teachers' Professional Development Course

In structuring the teachers' professional development course, an important role was played by the results of the questionnaires we administered to the high school students who participated in our activity with the RSA. In particular, we administered three questionnaires: one before the activity, one immediately after, and one four months after, so that we could investigate students' understanding and follow its evolution over time. Out of about nine classes who participated (for a total of about 200 students), we collected 154 answers. While the complete analysis can be found in Postiglione and Angelis 2021a, here we summarize the results relevant to the aim of this paper.

The first element that is evident from the questionnaires is the fact that the RSA approach helps to comprehend Newtonian gravity, already typically treated in school. This is particularly true concerning Kepler's second law, which was visualized better through the motion of the marbles on the sheet. Moreover, the activity proved to be useful to introduce more complex topics related to GR, such as the phenomenon of gravitational lensing and black holes. Another important aspect is that the rubber sheet makes it easier to connect apparently distant phenomena, such as the motion of the planets and the way a black hole looks, thus reinforcing the idea that the new Einsteinian description is perfectly coherent with the classical and most familiar framework of gravity (an idea that is very far from the common way of thinking, even that of teachers sometimes).

These considerations help us to select the topics that could have been effectively treated with teachers. In particular, we selected Kepler's laws, gravity assist, binary systems, gravitational lensing, and black holes. We also decided to dedicate some time to providing teachers with further ideas on the use of the rubber sheet not explored in depth, such as the formation of the Solar System, time dilation, and gravitational waves.

Another important aspect that we had to consider when using the RSA with teachers was the possible birth of misconceptions and wrong beliefs related to gravity. It is known from the literature (Kersting 2019, 2018; Price 2016; Gould 2016), for example, that one problematic aspect of the rubber sheet consists in leading to think that space–time is two-dimensional, and that gravity always points downward, as happens on Earth. In fact, the rubber sheet is almost two-dimensional, and the marble thrown on it orbits around the weight placed in the center and finally falls toward it. The same word "black holes" suggests an object, a hole, into which matter falls. "My marble can escape the gravitational attraction of the black hole: I can throw it upwards so that it leaps over the hole" is a thought that participants often shared with us during the experimentation with high school students. Of course, gravity doesn't work like that: matter is simply attracted in space, there is no bottom or top, above or below, but rather near/far in all directions. Black holes are spherical objects that attract the surrounding matter in all directions. Unfortunately, there is no way to visualize this using the rubber sheet. But this limitation can be made explicit, and students' considerations (such as the one cited above) can be used to make them reflect. This is the approach we used, and which proved to be effective: only 3% of our sample chose the distractor ("a force that points downward") between the alternatives when asked to specify what deforms space–time in the questionnaires administered after the activity (Postiglione and Angelis 2021a). We thus understood that we could suggest this strategy to the teachers.

Another critical point of the RSA is the fact that GR foresees the deformation of space and time, while the rubber sheet allows us to only visualize the spatial deformation (Kersting 2018). Similarly, to the misconception analyzed above, this is an intrinsic limitation of the model that cannot be overcome. One way to deal with it, however, is to explicitly address it and raise a discussion.

These reflections led us to understand the importance of dedicating a relevant part of our work with the teachers to the definition of the model used, the simplifications introduced, and to the way to guide the discussion with students so that they can really understand the topics treated without giving birth to wrong beliefs.

Once the issues to be covered were clear, we used another teachers' training course of the Department to test, optimize and finalize the methodology we developed. In particular, after a long and productive debate, we defined the guidelines and tricks necessary for the teacher to autonomously carry out our activity with the rubber sheet in their classrooms. As a last step, we thought of a structure for the space–time simulator that could be cheap, easy to build, and that could fit comfortably in the classroom.

At the end of our work, all the material was collected in a manual that was published in the form of an open-access eBook (Postiglione and Angelis 2020). The manual, designed at first for the Italian school, is written in Italian but also in English, in order to reach a wider audience, and is divided into eight educational cards, each of which deals with a certain topic. The first card provides the instructions to assemble the space–time structure, using a hula-hoop, some wooden strips, and a lycra sheet. Then, the concept of space–time and the model of the RSA are introduced, together with all the simplification implied and the suggestions that can help the teacher guide students to notice and overcome misconceptions. The other cards deal with specific topics related to Newtonian gravity (Kepler's laws, binary systems, gravity assist) and GR (gravitational lensing, black holes, time dilation). All the topics covered are treated by guiding the teacher step by step, starting from the materials to be used to show the phenomenon, how to use them, how to interact with students, and how to provide more insights by making use of appropriately chosen photos and videos. A more complete description of the manual can be found in a dedicated paper (Postiglione and Angelis 2021b).

In order to evaluate the response to the manual by readers, we added to it two questionnaires. The first one was designed to be completed after reading the book and concerns the readers' evaluation on the clarity and completeness of the description of the activities proposed, in addition to probing the teacher's intention to carry out the activities. The second questionnaire is instead dedicated to the readers who have already carried out the activity in the classroom and who can therefore evaluate the feasibility of realization, the students' reaction, and the efficacy in explaining the physics concepts.

4 First Reactions to the Developed Material

The manual we developed is available online[1] and until April 2021, more than 300 copies have been downloaded. In April 2021 we had received 22 responses to the first questionnaire. From these answers, we can gain a first idea of the teachers' reactions to the material we have developed.

In particular, the readers think that the book is interesting (the 68% give a score of 5/5, the remaining gives a score of 4/5), that the activities are presented clearly and in a complete way (72% give 5/5, the remaining 4/5). Moreover, the cards are useful (72% give 5/5, 23% give 4/5 and 4% give 3/5) and the content of the cards seems sufficient to carry out the activities in your classroom (68% give 5/5, 27% give 4/5). Regarding the simplicity of construction of the structure, the 40% give a score of 5/5, the 60% of 4/5 while the remaining give a score 3/5 (4%) or 2/5 (4%).

The 66% of the readers plan to realize the activity in the classroom (with a 23% of "*definitely yes*" and the remaining not sure about it), especially the ones dealing with the general introduction to the space–time, Kepler's laws (42,9%), gravity assist (33%), black holes (28%). However, the 38% share the intention of trying all the activities proposed. The reasons are many: the proposal is interesting and easy to realize, fun, useful, in line with the school program.

Regarding the year during which carrying out the activities, the 61% propose the fifth and last year of high school, as an introduction to Modern Physics, but also the third year (52%) when treating Kepler's laws.

Among the topics treated, Kepler's laws and black holes are the most cited among the favorites, while binary systems, gravitational lensing, and time dilation seem less preferred and therefore can be considered only as further insights.

These comments are in line with the considerations that came out from a focus group of teachers we organized to talk about the manual. In particular, these teachers appreciated the structure of the book, the way the activities are described and claim to be very curious to try the activities with their classes as soon as possible to give a more precise opinion.

[1] The manual can be found at the following link: https://www.edizioniefesto.it/collane/circuli-dimensio/379-sperimentare-la-gravita-con-il-telo-elastico-linee-guida-e-trucchi-experience-gravity-with-the-rubber-sheet-guidelines-and-tricks.

Although the answers to the first questionnaire show the teachers' will of experimenting the activity, we have not received yet answers to the second questionnaire, related to the realization of the activities by the teachers. This is probably also due to the current difficulty of carrying out activities in presence in schools due to the Covid-19 emergency.

5 Conclusions

In this paper we presented a teachers' professional development approach we realized at the Department of Mathematics and Physics of Roma Tre University with the aim of helping high school teachers to treat gravity in their classes using the rubber sheet analogy. Our methodology then resulted in a manual that contains the materials developed, that are freely available online.

Unfortunately, the Covid-19 emergency prevented us from following the teachers in their experimentation with their students. We believe, however, that our work represents a significant contribution to the demand of treating gravity using its most modern approach, General Relativity, and thus of introducing Modern Physics in high school. In particular, we believe that our proposal can help teachers to be autonomous in dealing with the topics proposed using interactive and engaging activities.

Our approach to gravity using the RSA proved to be valid and effective when tested with high school students because it helps them to visualize, comprehend and remember classical Newtonian gravity as well as some of the topics foreseen by GR. Regarding teachers, we believe that our approach was useful because it allowed a continuous debate with them on this topic; during the numerous discussions we had, teachers always declared to be willing to carry on the proposed activities with their students following the manual we developed, and this is also confirmed by the first results of the questionnaire attached to the book. Among the topics proposed, teachers seem to prefer Kepler's law and black holes, indicating that the rubber sheet can be used both to visualize and reinforce topics already typically treated in school and to introduce new and more complex topics.

For the future, we plan to continue our training with other teachers also in the courses we will organize in presence. Furthermore, we want to closely follow the activity as carried out by the teachers who already collaborated with the Department, investigating the clarity and effectiveness of the material we have collected in the manual. Finally, we plan to continue to monitor the evaluations of the activities as provided by the readers of the book.

References

Baldy E (2007), A New Educational Perspective for Teaching Gravity. *International Journal of Science Education*; 29 1767 https://doi.org/10.1080/09500690601083367

Farr B, Schelbert G and Trouille L (2012), Gravitational wave science in the high school classroom. *American Journal of Physics*; 80 898 https://doi.org/10.1119/1.4738365

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP (2014) Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences USA 111:8410–8415

Gould R R (2016) Why does a ball fall?: A new visualization for Einstein's model of gravity. *American Journal of Physics*; 84 396 https://doi.org/10.1119/1.4939927

Hake R (1998) Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. Am J Phys 66:64–74. https://doi.org/10.1119/1.18809

Kersting M (2018) Steier, R (2018) Understanding curved spacetime - the role of the rubber sheet analogy in learning general relativity. Sci Educ 27(7):593–623. https://doi.org/10.1007/s11191-018-9997-4

Kersting M (2019) Free fall in curved spacetime - how to visualise gravity in general relativity. *Physics Education*; 54 035008 https://doi.org/10.1088/1361-6552/ab08f5

Ministero dell'Istruzione (2010) dell'Università e della Ricerca, Indicazioni Nazionali. https://www.gazzettaufficiale.it/gunewsletter/dettaglio.jsp?service=1&datagu=2010-12-14&task=dettaglio&numgu=291&redaz=010G0232&tmstp=1292405356450

Pössel M (2017) Relatively complicated? Using models to teach general relativity at different levels. *Haus der Astronomie and Max Planck institute for astronomy Invited Talk at the Session of the Section Gravitation and Relativity at the Spring Meeting 2017 of the German Physical Society (DPG)* 2017

Postiglione A. and De Angelis I (2020) Sperimentare la gravità con il telo elastico: linee guida e trucchi. Experience Gravity with the Rubber Sheet: Guidelines and Tricks (Rome: Edizioni Efesto). https://www.edizioniefesto.it/collane/circuli-dimensio/379-sperimentare-la-gravita-con-il-telo-elastico-linee-guida-e-trucchi-experience-gravity-with-the-rubber-sheet-guidelines-and-tricks

Postiglione A. and De Angelis I (2021b) Experience gravity in the classroom using the rubber sheet: an educational proposal from the collaboration between university and school. *Physics Education*; 56 025019 https://doi.org/10.1088/1361-6552/abcab4

Postiglione A, De Angelis I (2021a) Students' understanding of gravity using the rubber sheet analogy: an Italian experience. Phys Educ 2021(56):025020. https://doi.org/10.1088/1361-6552/abd1c4

Price RH (2016) Spatial curvature, spacetime curvature, and gravity. Am J Phys 84:588–592. https://doi.org/10.1119/1.4955154

Prince M (2004) Does Active Learning Work? A Review of the Research. J Eng Educ 93:223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Thorne K (2009) Warping spacetime *The Future of Theoretical Physics and Cosmology: Celebrating Stephen Hawking's Contributions to Physics eds G W Gibbons, E P S Shellard and S J Rankin (Cambridge: Cambridge University Press)*

Scaffolding in a Fine-Grained Framework—Preparation of Physics Teachers for the Use of Sensors in Physics Experiments Planned by Pupils

Peter Demkanin

Abstract Within the preparation of future physics teachers in the third semester of their study, we realize an activity where they plan their own experiment in a secondary school student's role. This contribution offers one case study, where a student decided to plan an experiment with a basketball. We offer all major points of theoretical background behind this activity briefly. The activity is set to the participative socio-constructivist framework, the framework of The Learning Science approach. The activity is scaffolded by the teacher and is realized in the laboratory, which models a secondary school laboratory equipped with sensors and interfaces. Most of the students were not used to plan an experiment as secondary school students and this was the first activity of this type for them. Within this activity, students, well scaffolded by the teachers, were able to plan an experiment and well used some sensors. They also developed their abilities to manage such activities later in the position of teacher.

1 Introduction

There seems to be a common-sense assumption that physics education has a crucial role in developing young people for their subsequent university study of scientific and technological disciplines. Within physics education, we do not doubt the necessity that teachers should be able to apply, in their teaching, the knowledge pupils gained by various means. Our pupils are taught to get knowledge by their own activities—both, by activities with a textbook and by activities with equipment in a laboratory or terrain. Of course, physics education has a crucial role also in the education of pupils focused on most career-related, vocational education after primary and lower secondary education. Not so often is it discussed that physics education at secondary education also develops competencies relevant for students applying to study programmes as management or psychology. In this contribution, we discuss selected issues of relevance of utilization of sensors in physics education

P. Demkanin (✉)
Comenius University in Bratislava, Bratislava, Slovakia
e-mail: peter.demkanin@uniba.sk

J. Borg Marks et al. (eds.), *Physics Teacher Education*, Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-06193-6_16

at the secondary school level to develop competencies related to university study of secondary school graduates.

Incorporating sensors for the measurement of quantities in physics education is a topic frequently discussed last decades. Sensors for school measurements are now in every or almost every catalogue of equipment for education and on the market are available also low-cost sensors primarily intended for industrial use. Some sensors are built-in in smartphones, tablets, notebooks and even in smart clocks. It seems that discussing the utilization of sensors in physics education could be like carrying wood to the forest. Never mind. Or—probably this is one of the reasons for this contribution. What to do with the plenty of sensors around us? How to use them wisely?

Let's look deeper into some selected goals of physics education. As we wish (International Baccalaureate Organisation 2014), our pupils should strive to be inquirers, full of curiosity, learning with enthusiasm. She should develop and use conceptual understanding across a range of topics and use creative and critical thinking skills to analyze and take responsible action on complex problems. She strives to be able to express herself confidently and creatively and is able to cooperate with others. She takes responsibility for her actions and their consequences and also, she seeks and evaluates a range of points of view, willing to grow from the experience. The previous description of an ideal pupil, adapted from the International Baccalaureate learner profile (International Baccalaureate Organisation 2014), can expand by mentioning some subject-related competencies and related aims of physics education. Within the socio-constructivist and participatory approach, we would like the graduates of secondary schools to be able to plan, perform, evaluate and communicate a physics experiment. Planning an experiment means being able to formulate and justify a research question. To allow the pupil to present her curiosity, initiative and creativity, we do all our best to initiate her interest and allow her to independently select her own topic or issue for inquiry. This is probably the main difference between the acquisition and participatory framework of learning. In the acquisition framework, a school subject is portrayed as pre-given structures and procedures (Sfard and Cobb 2014), whereas the participatory framework portrays a school subject as a form of human activity. The acquisition framework holds that school subjects are an external body of knowledge discovered or constructed by experts and acquired or reconstructed by the learner (within the transmissive or constructivist framework). In contrast, the participatory framework holds that school subject is one of many human ways of doing things and it has evolved historically and continues to change (Sfard and Cobb 2014). The participatory framework we often present by the words 'pupil should, within formal physics education do, what she wants, at least sometimes' (Demkanin 2018).

Progress of use of sensors and other digital technologies in science education is fully consistent with the research results in The Learning Science, as presented on OECD/CERI International Conference 'Learning in the 21st Century: Research, Innovation and Policy'. The results bring the idea that there is a difference in the pre-assumptions of schooling itself. In the second half of the twentieth century, the model of schooling was based on the following pre-assumptions (never scientifically tested)

(Sawyer 2008): knowledge is a collection of facts about the world and procedures for how to solve problems; the goal of schooling is to get these facts and procedures into the student's head; teachers know these facts and procedures and their job is to transmit them to students; simpler facts and procedures should be learned first, followed by progressively more complex facts and procedures; the way to determine the success of schooling is to test students to see how many of these facts and procedures they have acquired. Graduates of schooling in the twenty-first century daily work with complex concepts. They need to be able and to learn to cooperate with others, express themselves clearly in both speaking and writing, understand scientific, mathematical, engineering and entrepreneurial thinking, possess integrated and usable knowledge, rather than the sets of decontextualized facts emphasized by instruction and take responsibility for their own learning (Sawyer 2008). One successful attempt of applying these ideas to a real activity with pupils of the age of 12 we presented in Demkanin and Kováč (2019). Pupils are instructed to plan a functional product and consider scientific, engineering, entrepreneurial sight and also functional design.

The use of digital technologies is inspired not only by progress in computer science and new digital technologies but, mainly, by progress in cognitive, educational and social psychology and by progress based on the deep research into how people learn. It is not a matter of asking teachers to use computers in their lessons. It is not easy to create the learning environments that result in deeper understanding, developed competencies and encouraging creativity. It is well known that students learn deeper knowledge when engaging in activities related to everyday activities as professionals who work in a discipline. This is a benefit, even a necessary condition for the innovative, creative economy. In our work, we try to follow the methodology or framework of Knowledge in Pieces. Knowledge in Pieces names a broad theoretical and empirical framework aimed at understanding knowledge and learning. It works with P-prims—elements of intuitive knowledge that constitute people's 'sense of mechanism,' their sense of which happenings are obvious, which are plausible, which are implausible and how one can explain or refute real or imagined possibilities (diSessa 2018). Within this framework, we try to systematically use a micro-analytic, fine-grained study of rich data sources of students thinking or learning. The teacher has a crucial role in the learning and in this contribution, we focus on the scaffolding of student's planning of an experiment. We analyze the use of scaffolding, five scaffolding intentions and six scaffolding means based on Van de Pol et al. (2019). The scaffolding intentions we use are: direction maintenance; cognitive structuring; reduction of degrees of freedom; recruitment; contingency management/frustration control. As scaffolding means we used feeding back, hints, instructing, explaining, modelling and questioning.

2 Scaffolding in Physics Teachers Education

What does it mean to learn? Probably the simplest but working definition could be the idea of Harlen (2005): learning is giving a sense to a new experience by the learner in interaction with others. A pupil at school interacts with others when discussing with a peer, group of peers, or the teacher. A pupil is in interaction with others also when working with a textbook (in interaction with the author of the textbook), working with a computer activity, or working in a software environment. For studying the role adults can play in joint problem-solving activities with pupils, Wood et al. (1978) introduced the metaphor scaffolding to label temporary support provided for the completion of a task that otherwise might not be completed. In this contribution, we focus only on the face-to-face teacher-student interaction, where the student is a future physics teacher. Scaffolding, in this view, is an interactive process between student—future physics teacher and university teacher (or trainer) when student performing a task. To use the concept of scaffolding for the assistance of teacher to students, the assistance should have three major characteristics, contingency, fading and transfer of responsibility. Contingency is often referred to as responsiveness, tailored, adjusted, differentiated titrated, or calibrated support (Van de Pol et al. 2019). For contingency, diagnostic strategies are important; the teacher must first determine the current level of competencies of the student. The second characteristic does not mean that after some scaffolds, the scaffolding cannot be used anymore. As fading scaffolding one issue, a scaffold for another issue can be initiated. Within fading, the responsibility is transferred to the student, the responsibility in the meaning of cognitive and metacognitive activities as well as at the level of effect. Transfer of responsibility does not mean that students, future physics teachers in the first semester of their study, cannot be responsible for their independent work. The responsibility, as the whole scaffolding, is related to performing a task that otherwise might not be completed by the particular students or by the group of students.

Scaffolding is classified as scaffolding intentions according to what we are scaffolding. We can scaffold the metacognitive, cognitive and/or affective level of the student. As we mentioned in the introduction, we usually intend to scaffold direction maintenance; cognitive structuring; reduction of degrees of freedom; recruitment; contingency management/frustration control (Van de Pol et al. 2019). These are presented in Table 1 and scaffolding means are presented in Table 2.

Table 1 Scaffolding intentions within the preparation of physics teachers, based on (Demkanin and Novotná 2021)

Support	What is scaffolded
Metacognition	Direction maintenance
Cognition	Cognitive structuring
Cognition	Reduction of degrees of freedom
Affect	Recruitment
Affect	Contingency management
Affect	Frustration control

Table 2 Scaffolding means within the preparation of physics teachers

How to scaffold	Short description
Feeding back	Provision of information regarding the student's performance to the student
Hints	Clues or suggestions to help the student to go forward
Instructing	What to do, how or why to do something
Explaining	More detailed information clarification
Modelling	Presentation of behaviour worthy of imitation, following, thinking aloud, demonstration of a particular skill
Questioning	Asking questions, which requires an active cognitive and linguistic answer

3 Sensors Available for Physics Education

Hopefully, most readers of this contribution have deep knowledge of sensors available. Never mind, let us move on. As we have already mentioned, for physics education, we can use sensors from catalogues of school equipment, sensors built-in in smartphones, tablets and notebooks, low-cost sensors primarily intended for industrial use. From the learner view, this classification seems to be not optimal. For our purposes, we have developed another classification. Let us imagine two pupils, 12 years old and 17 years old. And imagine, they both would like to measure a force necessary to keep a bottle hung on a thread at rest. They can use a spring newton metre, force sensor with a display (e.g. suitcase weight), force sensor designed for connection to an interface, force-sensing resistor, or even a kitchen scale. The first property we propose here to sort these is into two distinct parts, plug-and-play and designed for assembly. Both have a place in physics education, but their place is deeply different. Within this classification, plug-and-play are sensors that we switch on, or just connect to a suitable place and we see the measured value. This could be a sensor intended to connect to an interface (or computer), suitcase weight with display or kitchen balance. Sensors designed for assembly are all force measuring components, as force-sensing resistors. The sensors built-in, e.g. in a students' smartphone, we also can classify to these two distinct parts. As we have mentioned earlier, we are focusing on a learner's view. The use of a gravity sensor as an angle metre (protractor) in a smartphone with an application for this measurement we would classify as plug-and-play. The second property of a sensor from the learner view could be inbuilt availability to send the measured values for processing to be displayed in a graph. For a learner, there is a difference between sensors measuring (and displaying) single values only and sensors allowing (via an interface or a computer) displaying a series of measured values in a graph or a table. Using a kitchen scale, the learner can measure mass, or a force, as a single value only. Using a sensor connected to a datalogger student can measure, e.g. graph of a force exerting on a bouncing ball during the bounce. The third property from the learner's view is related to the necessity to calibrate the sensor before use. We could say that a sensor that needs to be calibrated before its use should not be classified as plug-and-play, but this could lead to some doubts. So, we prefer to use this as the third property.

Table 3 Some of the quantities of secondary school physics, for which plug-and-play calibrated sensors are available in our lab for the course Introduction to physics experiments

Quantity	Unit	Example range	Max. sampling frequency	Sensitivity
Force (pressure and thrust)	N	−50 to 50 N −5 to 5 N	100 kHz	0.003 N
Temperature	°C, K	−18 to 110 °C	100 kHz	0.07 °C
Temperature	°C, K	−200 to 1300 °C	4 Hz	0.4 °C
Air/gas pressure	kPa	0–700 kPa, 0–130 kPa	1 kHz	0.04 kPa
Light intensity	lux	0–1500 lux, 0–15 klx, 0–150 klx	3 kHz	0.4 lx
Distance	m	0.2–12 m	100 Hz	0.001 m
Distance	m	Smart pulley		0.02 m
Voltage	V	−10 to 10 V	100 kHz	0.008 V
Current	A	−5 to 5 A	100 kHz	0.004 A

4 Preparation of Future Physics Teachers—Experiment Planned by a Student

As a case study in this contribution, we present an example of the work of a student—future physics teacher in the 3rd semester of 5 year's study for the profession of Mathematics and Physics teacher. One of the main activities in the course, introduction to physics experiment, is focused on the development of the abilities of our students to plan an experiment in the secondary student's role. The course is realized in the laboratory, which is intended to model an average-equipped school laboratory. In Table 3, we bring quantities measured by plug-and-play calibrated sensors available at the lab, where our university students—future physics teachers planned their experiments. It is necessary to note that the students have available much more types of sensors later in their study, or also in this course on demand.

The maximal sampling frequency values in Table 3 do not take into account response time, so, e.g. in temperature sensor, 100 kHz is sampling of the sensor's temperature, not the temperature of the sensor surrounding.

5 Fine-Grained Framework and Use of Plug-and-Play Sensors, Case Study

Within activity focused on the development of abilities of students, future physics teachers to plan their own physics experiments, we monitored the use of plug-and-play calibrated sensors. The task was introduced by short instruction and a few pages of the textbook. Instruction: Plan an experiment. You may use whatever you have in this lab and what you can easily access—e.g. from home. Your result—plan of your experiment—will be marked on the criteria published in the textbook. In the textbook, the following criteria are briefly described: personal engagement; communication; formulation of a problem; hypothesis formulation; selection of variables and constants; design of the apparatus; method of data gathering and presenting.

One of the students decided to plan an experiment with a ball. She selected a ball and started with bouncing (Fig. 1).

She considered the bounciness and stiffness—she dribbled each of the balls, pressed each of them by her hand and selected one of them. She started to look for an interesting independent variable. This stage is formulated in more detail in Table 4.

In Table 4 selected parts of the discussion between the student and teacher are presented. The teacher allowed a wide margin of discretion and at the same time, scaffolded student to allow her to select a proper independent variable. It was not clear even for the teacher; what independent variable will be selected by the student, a high degree of contingency was present. Scaffolding was also provided in a manner that there was a clear focus on raising responsibility of the student, transfer of responsibility.

In this contribution, we continue with the details observed in the stage of apparatus design. The student took an air pump needle and inserted it into the ball (Fig. 2).

The student noticed, as described in Table 5, that the ball is open and successfully prepared the apparatus for pressure measurement, containing inflating needle, pressure sensor, plastic tube, valve and Luer-lock connector (from the pressure sensor equipment), WiLab wirelessly connected to computer, Fig. 3.

Fig. 1 Balls are considered by the student in the initial stage of planning her experiment

Table 4 Selected parts of the discussion between student and teacher, the initial stage of planning an experiment

Discussion	Type of scaffolding	Observation/note
Student: When dribbling a ball, the properties of the ball are important		Student well planned possible dependent variables related to dribbling, student bounced the ball few times
Teacher: Yes, you are true. But for experiment you need to take a measurable variable	Direction maintenance, questioning	Student, having the ball in her hand pressed the ball sometimes
Student: It depends on … how hard the ball is		
Teacher: Yes, are you planning to measure a force? We have good force sensors	Cognitive structuring, feeding back	
Student: It seems unusual to measure a property of a ball with force sensor		Student took the force sensor and tried to press the ball with the sensor
Teacher: Yes. How you can adjust the stiffness of a ball?	Reduction of degrees of freedom, hint	
Student: By a pump, we can inflate the ball. And we also can measure the pressure		Student looked happy and looked for air pump

Fig. 2 Inflating needle in a ball

She measured atmospheric pressure 101.2 kPa and independently realized that the pressure measured by the sensor is air pressure, not gauge pressure. The student independently inflated the ball, with a pump and another inflating needle and measured the pressure 146 kPa.

The student decided that the independent variable in her experiment will definitely be pressure. She also examined the range the pressure will change when manipulating the ball. She pressed it with her had in different ways and saved the graph of pressure

Table 5 Selected parts of discussion between student and teacher, apparatus design

Discussion	Type of scaffolding	Observation/note
Student: Now I have the needle in the ball, so I can change the pressure and also can measure it with the pressure sensor		Student pressed the needle to the ball, Fig. 2 and looked at the teacher
Teacher: Yes, just continue	Contingency management, feeding back	Student continues in apparatus design
… *1 min later* …		
Teacher: By the way, can you estimate the pressure in the ball now? (looking at the ball on Fig. 2)	Reduction of degrees of freedom, questioning	Student seems surprised, looks at the ball
Student: No, I can try how hard the ball is. … I would estimate quite low pressure. I see here (pointing in the info on the ball) pressure 0.25 bar, what is 25 kPa. So I estimate half of this pressure		
Teacher: Look at it deeply. Is the ball inflated now?	Cognitive structuring, questioning	
Student: Yes, the ball is open. The needle is open. So there is zero pressure now		Student seems happy
Teacher: Measure it, continue in setting the apparatus	Direction maintenance, instructing	

Fig. 3 Left: Apparatus for measurement of pressure, in the process of apparatus design. Right: Air pressure in the ball measurement in Coach 7

vs time during these manipulations, Fig. 4. She released that the pressure was slowly lowering during this manipulation.

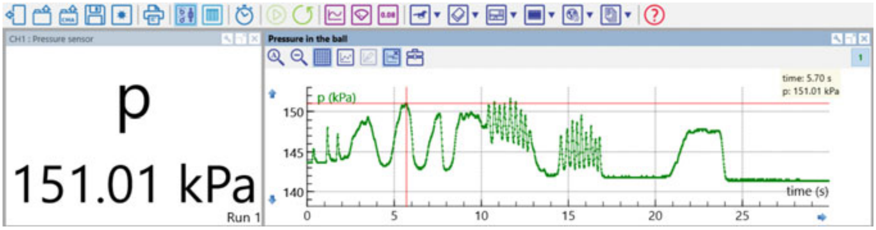


Fig. 4 Pressure changes during ball handling

6 Discussion

In this contribution, we described some of the stages of planning an experiment by a university student, future physics teacher, in the role of a secondary school student. The student, well scaffolded was able to do what she would not be able to do without support. Proper utilization of sensors together with proper methodology, allows students to realize their plans and, the student's plans could be much more challenging. Similar activities we performed some years ago in a laboratory not equipped with sensors were reported by the students as not inspiring enough for their future profession of physics teacher. This activity helps students as future physics teachers to understand that physics is not only a collection of facts discovered in the past by some geniuses but that physics offers a lot also for the realization of student's plans and development of their creativity. Students must do what they want, at least sometimes. Our students, future physics teachers, understood the role of such activity in the curriculum of secondary school physics. The competency to use sensors in a meaningful way was raised significantly. The abilities of students were tested one month later. They were asked to plan an experiment in which they will use a radio-controlled toy helicopter. Students had to design their plans without access to the lab, which was caused by Covid pandemic. During reflection of this series of activities we released, that graded activity, for summative assessment, in planning experiment in a role of a secondary school without access to a lab, as a homework, was inspiring as a proper way of testing abilities to plan a physics experiment also for a face-to-face course.

Another activity of the course introduction to physics experiments, much more complex, is used as an example of the possible evolvement of physics education in Demkanin (2020). Via such activities future physics teachers learn, in concrete contexts, to develop creativity and critical thinking of their future pupils (Velmovská et al. 2019). To implement such activities in a brain-friendly environment, raising well-being of the pupils as well as teachers, we plan to check whether we adhere to the principles and tenets of learning recently formulated by Tokuhama-Espinosa and Nouri (2020) and whether we teach future physics teachers develop the pillars of the mind of their pupils (Tokuhama-Espinosa 2019).

Acknowledgements This work has been supported by the Scientific Grant Agency of the Ministry of Education, under the contract VEGA 1/0273/19, Tutoring and Scaffolding in the Preparation of Pre-Service Physics Teachers.

References

Demkanin P (2018) Concept formation: physics teacher and his know-how and know-why. J Balt Sci Educ 17:4–7. https://doi.org/10.33225/jbse/18.17.04
Demkanin P (2020) The ways the theory of science education can evolve. J Balt Sci Educ 19:860–863. https://doi.org/10.33225/jbse/20.19.860
Demkanin P, Kováč M (2019) Effective individual work of pupils within physics education in the light of the learning sciences. AIP Conf Proc 2152:020002. https://doi.org/10.1063/1.5124742
Demkanin P, Novotná S (2021) Selected aspects of tutoring and scaffolding pre-service physics teachers. In: Inted2021 proceedings, 8710–8716. https://doi.org/10.21125/inted.2021.1814
diSessa AA (2018) A friendly introduction to 'knowledge in pieces': modeling types of knowledge and their roles in learning. In: Invited lectures from the 13th international congress on mathematical education. Springer, pp 65–84. https://doi.org/10.1007/978-3-319-72170-5_5
Harlen W (2005) Teaching, learning and assessing science 5–12. SAGE Publications
International Baccalaureate Organisation (2014) Physics guide
Sawyer RK (2008) Optimizing learning: implications of learning sciences research. In: OECD/CERI international conference 'learning in the 21st century: research, innovation and policy'. CERI
Sfard A, Cobb P (2014) Research in mathematics education' what can it teach us about human learning? In: Sawyer RK (ed) The Cambridge handbook of the learning sciences. Cambridge University Press, Cambridge, pp 545–564
Tokuhama-Espinosa T (2019) Five pillars of the mind: redesigning education to suit the brain. W. W. Norton & Company
Tokuhama-Espinosa T, Nouri A (2020) Evaluating what mind, brain and education has taught us. In: Access: contemporary issues in education 40: 63–71. https://doi.org/10.46786/ac20.1386
Van de Pol J, Mercer N, Volman M (2019) Scaffolding student understanding in small-group work: students' uptake of teacher support in subsequent small-group interaction. J Learn Sci 28:236–239. https://doi.org/10.1080/10508406.2018.1522258
Velmovská K, Kiss T, Trúsiková A (2019) Critical thinking and physics education. AIP Conf Proc 030037. https://doi.org/10.1063/1.5124781
Wood D, Wood H, Middleton D (1978) An experimental evaluation of four face-to-face teaching strategies. Int J Behav Dev 1:131–147. https://doi.org/10.1177/016502547800100203